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1. FOOD SCIENCE AND TECHNOLOGIES

IMPROVEMENT OF THE TECHNOLOGY OF MEAT PASTRY SEMI-FINISHED PRODUCTS USING GLUTEN-FREE VEGETABLE RAW MATERIALS

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Abstract. *Comprehensive studies have been carried out, which allow theoretically and experimentally justifying the introduction of gluten -freeing vegetable raw materials, hereinafter gluten-free vegetable raw materials, as a physiological and functional ingredient for the formation of consumer properties and increasing the biological value of meat dough semi-finished products. The choice of gluten-free vegetable raw materials as a physiological-functional ingredient of semi-finished meat dough was scientifically justified; the main functional-technological properties and physical-chemical parameters were investigated. The optimal ratio of gluten-free vegetable raw materials and auxiliary ingredients in the recipe of meat dough semi-finished products was established. The choice of components was theoretically justified and the formation of the optimal recipe composition of minced meat dough semi-finished products was carried out. The recipe and production technology of meat dough semi-finished products using gluten-free vegetable raw materials - "Gluten -free" dumplings have been developed. The organoleptic and physical-chemical indicators, nutritional and energy value, main safety indicators and expiration dates of semi-finished meat dough products were studied.*

Key words: meat dough semi-finished products, minced meat, gluten -free vegetable raw materials, dietary food, celiac disease, dumpling technology, model dough systems, protein, protein, rice flour, sorghum flour, flax flour.

I. INTRODUCTION

At the current stage of development of modern society, there is a need to apply new science-based solutions for the production of specialized food products. This is due to an increase in the number of people suffering from hereditary diseases of the gastrointestinal tract. According to statistics, the average prevalence of celiac disease among the population of Ukraine is 1:200, but in recent years, a positive trend towards its growth has been observed.

Thanks to progress in the field of diagnosis of chronic diseases, as well as medical and clinical experience regarding the possibility of a comfortable existence for celiac disease patients , it has been established that adherence to an adequate lifelong gluten -free diet is the only way to restore body dysfunctions and maintain quality of life.

As the review of literary sources shows, the most promising types of gluten -free raw materials widely used in the production technology of specialized food products are rice flour, sorghum flour, amaranth flour, flax flour and corn starch.

The use of gluten-free vegetable raw materials, which has different nutritional and biological value, functional-technological and rheological properties, the use of

innovative methods of component modification allows to significantly reduce the need to use a large number of auxiliary structure-forming components. And thereby ensure the stability of the quality of manufactured food products and obtain food products balanced in composition.

Gluten -free food products is strictly regulated by the provisions "On the safety of certain types of specialized food products, including dietetic-curative and dietary-prophylactic food". Despite this, as shown by analytical data and the results of inspection control studies, the composition of some types of such products does not meet the mandatory safety and quality requirements. Most of the gluten -free food products produced are characterized by insufficient content of complete protein, vitamins, reduced organoleptic characteristics, short shelf life, high cost and, in some cases; do not meet the specifications declared by the manufacturer.

Meat semi-finished products are a source of plant and animal protein, some essential nutrients necessary for normal human growth, development and life. In this regard, it can be assumed that the use of meat semi-finished products with the use of gluten-free vegetable crops will eliminate protein-energy and iron deficiency in the human body.

The lack of the required amount of scientific research in the field of production of specialized meat semi-finished products requires the expansion of theoretical knowledge and the evidence base, which determines the necessity and relevance of the development of technology for the production of meat semi-finished products of high nutritional and biological value for the nutrition of people suffering from gluten allergy (celiac disease) and healthy food in general.

The expediency of combining different types of gluten-free vegetable raw materials, which differ in functional-technological, structural-mechanical properties, chemical composition and biological value as components of semi-finished meat, which provide high biological value and optimal properties of the dough system, has been scientifically substantiated and experimentally confirmed.

The technology for the production of meat semi-finished products using gluten-free vegetable raw materials for consumers suffering from celiac disease has been developed, the nutritional and biological value, physical-chemical and organoleptic indicators of the product have been determined.

Taking into account the primary importance of a gluten -free diet in the prevention and treatment of celiac disease , the production of new types of specialized gluten -free food products , maximally balanced in terms of nutrient composition and sensorial adequate to the consumer properties of traditional analogues , is gaining special relevance.

II. LITERATURE ANALYSIS

Having analyzed a large volume of scientific research works in the field of clinical diagnosis and therapy of celiac disease. it was established that the only effective and most accessible possibility of improving the patient's condition and normalizing the gastrointestinal tract remains adherence to a lifelong diet based on the selection of an adequate gluten -free diet, taking into account the age, characteristics of the patient's condition in period of the disease [1,2].

Diet is based on the principle of consumption of carbohydrate components provided by the use of gluten -free cereals and flour, vegetables, fruits and berries. The presence of protein and fat products in the diet (low-fat varieties of meat, eggs, dairy products, vegetable and animal fats) is important for the diet. Assessment of the perspective of using plant raw materials, based on their composition and properties, is described and cited in many scientific works of domestic and foreign scientists [3-5].

Of particular interest are scientific works on the study of model dough systems with amaranth flour, which can serve as a basis for further research. In their research, the authors determined that monolithic amaranth particles, consisting of starch tightly bound to protein, give the dough elastic properties [5-7].

The proposed recipe for the production of gluten -free confectionery products based on rice flour. The authors scientifically substantiated that the compositional ratio of rice flour and starch 1:1 allows to reduce the need to use sodium bicarbonate (up to 40%), to optimize the indicators of humidity, wetting and to improve the organoleptic characteristics of gluten -free cookies, which gave an impetus to the expansion of the product range of this segment [8 -10].

Another vegetable crop of the oleaginous family, which is widely used in the recipes of specialized and functional food products, is flax and its processing products. The authors have scientifically substantiated the technology of obtaining flax flour with different lipid and protein content. The introduction of flax flour into the recipe helps to improve the elastic properties of gluten, values of effective viscosity, indicators of specific volume and porosity of bread [11, 12].

In recent years, scientific interest in researching the properties of sorghum and its processing products in various food systems has grown significantly. This is primarily based on the unique technological properties of this vegetable raw material. A number of works by domestic and foreign scientists have been devoted to the study of the chemical composition of sorghum of various varieties [13]. The chemical composition of sorghum flour is described in detail in numerous works of scientists [14].

The problem of improving the quality of gluten -free products remains an open question for experts in the food industry all over the world. Forming high-quality physical-chemical and organoleptic indicators of food products is a complex technological task. Therefore, improving the technology of meat dough semi-finished products using gluten -free vegetable raw materials is an urgent task today.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

Formulation of the purpose of the work. Improvement of the technology of meat dough semi-finished products and establishing the optimal ratio of gluten-free vegetable raw materials and auxiliary ingredients in the recipe of meat dough semi-finished products, researching their organoleptic and physical-chemical indicators, establishing nutritional, biological value, main safety indicators of meat dough semi-finished products, determining expiration dates.

The object of the research is meat semi-finished products using gluten-free vegetable raw materials.

The subject of the research is meat semi-finished products using gluten-free vegetable raw materials.

Research methods: modern methods of chemical, physical-chemical, organoleptic, microbiological research, as well as methods of mathematical processing of the obtained data.

IV. RESULTS

Because the chemical composition of gluten-free vegetable raw materials can affect the functional-technological and rheological properties of dispersed systems, at the next stage, a study of their chemical composition was conducted, the results of which are presented in Table 1.

Table 1. Chemical composition of gluten-free vegetable raw materials

α=0.05

Name	Moisture, %	Protein, %	Carbohydrates, %	Fat,%	Ash, %
Rice flour	10.6	7.9	78.6	2.5	0.4
Sorghum flour	8.3	24.3	57.2	6.8	3,4
Flax flour	6.0	33.8	36.5	18.9	4.8
Amaranth flour	6.9	8.6	75.3	6.4	2.8
Cornstarch	11.3	1.0	87.3	0.1	0.3

As can be seen from the above data, flax and sorghum flour differ in their high protein content, which determines high structure-forming properties, at the same time, the high fat content limits the use of this type of gluten-free vegetable raw materials in large quantities in the recipes of semi-finished products that require long storage periods. Rice, amaranth flour and corn starch, due to the presence of a large amount of starch polysaccharides and the ability to pasteurize at low temperatures, will provide model dough systems with the necessary rheological characteristics, reduce caloric content and enrich the product with highly digestible carbohydrates.

The dynamics of biochemical changes and transformations of the main components of gluten-free vegetable raw materials during dough kneading are correlated with the functional and technological properties of the raw materials, such as: fat-absorbing capacity (FAC), water- absorbing capacity (WAC), water- holding capacity (WHC) and fat -holding capacity (FHC), which allow justify the choice of technological parameters of the dough. Flour and starch with a temperature of 23±2°C were used for experimental research.

The results of the study of the functional and technological properties of gluten-free vegetable raw materials are presented in Table 2.

Table 2. Functional and technological properties of gluten-free vegetable raw materials

α=0.05

Name	WHC,%	FAC, %	FHC, %	WAC, %
Wheat flour	89.3	109.0	91.4	109.0
Rice flour	93.5	107.6	82.2	146.0
Amaranth flour	89.9	108.7	91.3	182.0
Sorghum flour	95.1	122.0	95.4	188.0
Flax flour	124.3	115.0	110.3	289.0
Cornstarch	77.3	102.0	80.1	103.6

Experimental data show that flax flour has the maximum indicators of WHC, FHC, and the highest level of FAC (122%) is noted in sorghum flour. These results are due, first of all, to the ratio of the main groups of biopolymers and the fractional composition of proteins of the raw material. The high content in flax and amaranth flour of water-soluble proteins (albumins -up to 44% and 57%, respectively) and non-starch polysaccharides, characterized by high hydrophilicity, determines the maximum values of WHC and swelling. The presence in rice flour of starch polysaccharides (up to 55%), the alcohol- soluble fraction of protein (glutenins) up to 70% of the total fractional composition, as well as in wheat flour up to 50% of amino acids with pronounced hydrophobic properties, determines the low values of WHC and FHC.

The obtained results emphasize the necessity of using rice, amaranth and sorghum flour in the formulation of gluten -free flour mixture. This fact is confirmed by the analysis of studies obtained during the study of structural and mechanical properties and chemical composition of raw materials. The prospect of compositional supplementation with flax flour is due to the possibility of increasing the functional and technological properties of the gluten -free flour mixture, due to the high indicators of WAC, FAC, WHC, FHC, the presence of a large amount of fats and pentosanes, which have a cryoprotective effect and increase the plasticity of the dough.

In the production of gluten -free dumpling dough, flour and starch were used that meet the basic requirements for the gluten content in gluten-free vegetable raw materials (<10 mg/kg).

Taking into account the results of the research, the compositions of gluten -free dumpling dough were produced in a batch of experimental and control samples of frozen dough semi-finished products according to the table. 3 recipes.

Table 3. Recipes of control and experimental samples of dumplings

Raw materials, spices and materials	Rate of expenditure	
	Control sample	"Gluten-free" dumplings
Main raw material, kg/100 kg of unsalted raw material		
Ribbed beef	34.7	34.7
Meat of broiler chickens	14.0	14.0
Raw fat	5.0	5.0
Wheat flour	35.0	-
Gluten-free flour mixture*	-	33.4
Chicken eggs are edible	3.2	4.0
Fresh onion	7.3	7.3
Olive oil	-	0.8
Vegetable sunflower oil	0.8	-
Auxiliary raw materials and materials, g/100 kg of raw materials		
Ground black pepper/allspice	100	100
Coriander	100	100
Garlic is fresh	100	100
Food kitchen salt	1700	1700
Wheat flour for dusting	1000	-
Rice flour for dusting	-	1500

* Gluten-free flour mixture (kg): rice flour -23.2; sorghum flour -5.2; flax flour -1.2; corn starch -3.8.

During the production of the dough, drinking water was used for control samples of dumplings. The duration of dough kneading was carried out until the dough had a plastic, uniform consistency, and for control samples of dumplings, it was about 15 minutes. After kneading the dough, it was supposed to be kept for 40 minutes at a temperature not higher than 20-25°C. Manufactured control and experimental samples of dumplings were examined according to the main quality indicators. In the course of research on the chemical composition, the content of food substances and the energy value of dumplings were determined (Table 4).

Table 4. Chemical composition of control and experimental samples of dumplings

α=0.05

The name of the dumpling sample	The mass fraction,%					Energy value/ Caloric value, kJ / kcal
	moisture	protein	fat	carbohydrates	ashes	
Control	53.5	11.6	11.3	22.5	1.1	973/226
"Gluten-free" dumplings	54.6	12.1	11.7	20.3	1.3	962//230

On the basis of the obtained research results, it was established that "Gluten - free" dumplings are characterized by an increased content of moisture, protein and fat. The ratio of these nutrients (1:1:4.5) in experimental samples of semi-finished products is close to the optimal assimilation of the product by the human body (1:1:4).

The output of the control sample of dumplings is 121%, "Gluten - free" dumplings- 124%. The mass fraction of moisture of gluten -free dumpling dough, determined by calculation, was equal to 42%, wheat - 40%. The temperature of gluten -free dumpling dough was 27±1°C, the control sample of dumpling dough was -26±1°C.

In the course of the experimental tests, it was established that the control and experimental samples of dumplings correspond to the main quality indicators characteristic of this type of semi-finished products. On the basis of the conducted tasting studies, it was established that "Gluten - free" dumplings are characterized by a plastic, soft and homogeneous dough consistency, while the control samples of dumplings have a more elastic and dense dough shell. Minced frozen dough semi-finished products were characterized by a uniform juicy consistency, without visible inclusions of connective tissue. To achieve the best organoleptic characteristics of the finished product, it is recommended to cook "Gluten - free" dumplings for 6-7 minutes.

According to the regulation "On the safety of meat and meat products", frozen semi-finished products in the dough must meet the safety indicators - in terms of the content of toxic elements, antibiotics, pesticides and radionuclides. Hygienic requirements and indicators of "Gluten - free" dumplings are presented in Table 5.

Table 5. Hygienic requirements and safety indicators of "Gluten - free" dumplings

Name of substance (element)		The permissible level of its content, mg/kg (for radionuclides - Bq /kg), no more	Test results
Toxic elements:	Lead	0.5	Not found
	Arsenic	0.1	Not found
	Cadmium	0.05	Not found
	Mercury	0.03	Not found
Radionuclides:	Cesium-137	200	Not found

According to the obtained results of the studied safety indicators, it can be concluded that no toxic elements and radionuclides, which cause food poisoning and

toxicosis in the human body, were found in «Gluten - free" dumplings.

“Gluten – free” dumplings have established expiration dates not more than two months from the moment of manufacture at a storage temperature not higher than -18°C.

V. CONCLUSIONS

Based on a set of experimental studies, it can be stated that an effective way to improve the quality of gluten -free dumpling dough is to combine gluten -free types of flour and starch with different functional and rheological properties, nutritional and biological value. It was established that the recipe composition of the gluten -free flour mixture should include 69.46 %- of rice flour, 15.57 % -sorghum flour, 3.59 % - flax flour and 11.38 % -corn starch.

Based on the results of experimental studies, the ratio of main and auxiliary components was obtained, the recipe and technology for making "Gluten - free" dumplings was developed. Based on the obtained research results, it was established that "Gluten - free" dumplings are characterized by an increased content of moisture, protein and fat. The ratio of these nutrients (1:1:4.5) in experimental samples of semi-finished products is close to the optimal assimilation of the product by the human body (1:1:4).

According to the obtained results of the studied safety indicators, it can be concluded that there are no toxic elements and radionuclides that cause food poisoning and toxicosis in the human body in "Gluten -free" dumplings. "Gluten -free" dumplings have established expiration dates not more than two months from the moment of manufacture at a storage temperature not higher than -18°C.

"Gluten-free" dumplings are a high-quality and biologically valuable product for dietary nutrition and contribute to the expansion of the range of gluten -free products.

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THE EFFECT OF DIFFERENT STORAGE TEMPERATURES AND LIGHT EXPOSURE ON CAROTENOID STABILITY OF MARIGOLD FLOWERS (*Tagetes erecta* L.)

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Abstract. *Marigold (Tagetes erecta L.) is a medicinal and ornamental plant widely known for its health-promoting properties and its coloring effect on poultry skin and egg yolk. These properties result from the high content of bioactive ingredients, i.e. carotenoids, which are sensitive to environmental factors such as temperature, light, and oxygen. The aim of the study was to investigate the effect of temperature (4, 25 and 40 °C) and light exposure on the content and degradation of total carotenoids (TC) in two marigold meals during storage period of 77 days. The initial TC content in meal B (13.63 mg/g DM) was higher than the initial TC content in meal A (10.35 mg/g DM) due to the dilution effect of the leafy parts (high chlorophyll concentration). The lowest TC content was found in both meals (A and B) in the samples stored at 40 °C (6.09 mg/g DM and 5.88 mg/g DM, respectively). Consequently, the highest TC degradation percentages and rates were obtained in both meals when stored at 40 °C (41.15 vs. 56.95% and 0.0065 vs. 0.0099 day^{-1}, respectively). Exposure of the meals to light contributed to TC degradation. The optimal conditions for storage of marigold flowers were found to be 4 °C and 25 °C without exposure to light. Although the recommended storage temperatures for carotenoid sources are close to 0 °C, the results suggest that storage at 25 °C without exposure to light could be a cost-effective alternative.*

Keywords: *marigold flower (Tagetes erecta L), total carotenoids, degradation, storage conditions*

I. INTRODUCTION

The use of edible flowers as food supplements dates back to ancient times, as they positively affect the organoleptic properties of traditional foods and have a decorative effect [1-3].

The most commonly used were ornamental flowers such as mallow (*Malva sylvestris*), acacia (*Robinia pseudoacacia*) [1], dahlia (*Dahlia mignon*), calendula (*Calendula officinalis*), and marigold (*Tagetes erecta* L.) [1,3]. Over the past few decades, due to the great interest in gastronomic innovations and functional foods [1,3], numerous scientific studies have been conducted on the nutritional and health-promoting properties of edible flowers. Plant tissues, including flowers, are rich in bioactive compounds such as polyphenols, carotenoids, vitamins, and essential oils [1-3], which have shown antioxidant [1,3,4], hypoglycemic [3,4], antimicrobial [3,5,6], anticancer [8,9] and anti-inflammatory properties [10], beneficial effect on degenerative retinal diseases [7], and other health-related benefits.

The content of these phytochemicals in plant flowers depends on the plant species. Anthocyanins, a subclass of the polyphenol family, for example, are characterized as blue, purple, and reddish pigments [1,3,11], which are abundant in blue peas (*Clitoria ternatea*) [11]. On the other hand, carotenoids are recognized as yellow and orange pigments [1,3] found in citrus fruits, vegetables (corn, watercress, carrot, sweet potato, tomato) [13] as well as ornamental flowers such as chrysanthemum (*Chrysanthemum crassum*) and marigold [14].

Marigold is an ornamental annual plant native to Mexico [15] and its flowers are considered an important source of carotenoids, especially lutein, zeaxanthin and β-carotene [15-17]. According to literature data [14,18], lutein and its esters comprise more than 80% of carotenoids found in marigold petals. Therefore, marigold is widely used in poultry nutrition as an affordable feed additive that improves the colour of poultry skin [19] and egg yolk [17,19-26]. Furthermore, due to the higher content of carotenoids (especially lutein) in eggs, consumption of these enriched eggs may also reduce the risk of age-related macular degeneration [19,20,27,28], cataracts [26-28], and damage of eye photoreceptors caused by blue light [19].

One of the carotenoid properties is their sensitivity to light, heat, presence of oxygen [14,29,30], acidity, water content [30] and enzymatic factors [30] during storage and post-harvest processes. In order to achieve the full nutritional potential of marigold flowers, the stability of their carotenoids during storage should be investigated.

II. LITERATURE ANALYSIS

Growing consumer awareness about the negative health impact of synthetic food supplements (colorants, antioxidants, flavour enhancers) led scientists to explore the possibility of using ornamental and medicinal plants as a source of carotenoids in human and animal nutrition. Many studies have been conducted to determine the composition of carotenoids in different fruits, vegetables and cereals [27,31,32]. However, there is a scarcity of data in literature on determining the carotenoid composition of ornamental plants.

Marigold is one of the few ornamental flowers whose carotenoid profile has been thoroughly investigated [33,34]. Nevertheless, little attention has been given to the influence of harvest and postharvest processes on carotenoid retention; only a few studies could be found in the available literature. Kurniawan et al. (2019) investigated the effects of several drying methods on the content of all-*trans* isomers of lutein and zeaxanthin: freeze drying (-45 °C), sun drying (39 °C), vacuum oven (40 °C) and conventional oven drying (40 and 100 °C) methods [35]. The authors showed that drying treatments at high-temperature caused carotenoid degradation due to the isomerization. Higher lutein and zeaxanthin contents were observed in marigold flowers dried using lower – temperature methods (freeze drying and vacuum oven), while sun drying proved to be an affordable alternative method. Similar results were observed in the study by Siriamornpun et al. (2012) [17], where freeze drying (-40 °C) and far-infrared radiation with hot air convection (40 °C for 60 min) resulted in highest lutein and lycopene content. Hot air drying (40 °C for 4 h) resulted in the highest

content of β-carotene. These results indicate that not only the different drying methods lead to changes in carotenoid content, but also that temperatures during storage could cause the degradation of carotenoids.

According to the available literature data, the effect of storage conditions on the carotenoid composition of marigold flowers is a poorly explored area. Akshaya et al. (2017) [16] investigated the effect of three different storage temperatures (-20 °C, 4 °C and 25 °C) on the retention of carotenoids during 60 days of storage. The study revealed that carotenoid degradation was lowest when marigold flowers were stored at -20 °C, followed by 4°C and 25 °C, regardless of variety. In general, further analyses of the effects of temperature and other storage conditions (e.g. exposure to light) on marigold flowers are required. Therefore, aim of the present study was to investigate the effect of temperature (4, 25 and 40 °C) and exposure to light on the content and degradation of total carotenoids (TC) in two marigold flower meals during storage of 77 days.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

Two batches of marigold flower meals (*Tagetes erecta* L.) were obtained from the manufacturer TRAKO-AGROLUDBREG d.d. (Ludbreg, Croatia). Marigold flower meals differed in the parts of the plant used for their production – by grinding the whole flowers (A) or by grinding only the petals (B; Figure 1.). Regardless of which part of the plant was used for production, they were air-dried and ground after collection.

Figure 1. Two marigold flower meals used in the study prepared from whole flowers (A) and only from the petals (B)

Sample preparation and storage conditions. Each batch of marigold flower meal was thoroughly mixed and diveded into 12 parts. About 50 g of each part was sampled in a plastic container with a screw on cap; in total, there were 24 containers.

The prepared containers with meals were stored at four different conditions during 11 weeks:

- 4 °C in the dark (stored in the refrigerator),
- 25 °C in the dark (sample wrapped with aluminum foil, stored in a incubator without a light source),
- 25 °C exposed to light (stored in a incubator with a light source),
- 40 °C in the dark (stored in a incubator without a light source)

For each marigold meal, there were three replicates (three containers) for each storage condition (2 marigold meals × 4 storage conditions × 3 replicates), and the experiment was set up according to the completely randomized design. From each plastic container, samples for analysis were taken on day 0, 7, 14, 21, 28, 35, 49, 56, 63 and 77 of the experiment.

The analysis was carried out immidiately after sampling. All samples were ground using the ball grinder (MM 200, Retch, Germany) and the moisture content was determined by drying at 103 °C for four hours.

Carotenoid extraction. The procedure was performed using hot saponification and subsequesnt extraction of the carotenoids with hexane. Briefly, 50 mg of the sample was weighed into a 15 mL glass tube. Then, 300 μL of ethanol containing 12% of the antioxidant BHT (2,6-di-tert-butyl-4-methylphenol) and 200 μL of the solution of the internal standard trans-β-apo-8′-carotenal (Sigma Aldrich, Germany) were pippeted in each tube. After mixing, 6 mL of methanol (containing 6% of KOH) was pippeted into each tube and the mixture was homogenized (T10, Ika, Germany; 30s at maximum speed of rotation). The samples were then incubated at 60 °C in water bath (Waterbath, 5L, Cole Parmer, USA) for 15 min. Immidiately after incubation, the tubes were placed in ice bath. To each tube, 3.5 mL of 10 % NaCl was added, followed by 2.5 mL of hexane. The mixture was vortexed for 30 s and the tubes were centrifuged (5 min, 4000 rpm; Centric 322A, Tehtnica, Slovenia). The upper hexane layer was separated into a separate tube and the extraction procedure with hexane was repeated until the hexane layer had discoloured (typically 11 times). After extraction, the combined hexane extracts were evaporated using a rotary vacuum concentrator (RVC 2-25CD plus, Martin Christ, Germany). The dry residue was dissolved in 200 μL of acetonitrile:methanol:dichloromethane (45:20:35, v/v/v).

Carotenoid quantification. The separation and quantification of carotenoids were carried out according to RP HPLC method described by Kurilich and Juvik (1999) [36]. The column system was composed of two sequentially connected C18 reversed-phase columns, Vydac 201TP54 (5 μm; 4.6 × 150 mm; Hichrom, Reading, UK) and Zorbax RX-C18 (5 μm; 4.6 × 150 mm; Agilent Technologies, USA). The columns were protected by Supelguard Discovery C18 guard column (5 μm; 4 × 20 mm; Supelco, USA) by a C18 protection column. The SpectraSystem HPLC instrument (Thermo Separation Products, Inc., USA) consisted of a quaternary gradient pump (P4000), a degassing system (SCM 1000), an autosampler (AS3000), a column heater and a UV/VIS (UV2000) detector. The mobile phase consisted of acetonitrile:methanol:methylene chloride (75:20:5, v/v/v) containing 0.05% triethyl-amine and 0.1% BHT. The mobile phase flow was set to 1.8 mL/min at room temperature, while the samples were injected using a 20-μL loop. The carotenoids were detected at 450 nm, and the total run was 40 min.

The sum of areas of all peaks separated during the run was identified as total carotenoids, and the content of total carotenoids was quantified as β-carotene equivalents by external standardization with calibration curve of β-carotene (Sigma-Aldrich, Germany; $r^2 = 0.99$). Each replicate was anlysed in duplicate and the mean value was taken as the result.

Kinetics of Carotenoid Degradation and Data Analysis. Kinetics of carotenoid degradation during storage was calculated by first order kinetics (Hidalgo and Brandolini (2008) [31] according to the equation:

$$C=C_0 \times e^{-kt}$$

where C is defined as a concentration of total carotenoids at the time (t) during storage (day 0, 7, 14, 21, 28, 35, 49, 56, 63 and 77), C_0 as the initial or carotenoid content at the beginning of storage, and k is degradation rate (day^{-1}).

SAS statistical software (version 9.4) [37] was used for the nonlinear curves data processing. Nonlinear parameters of carotenoid degradation that follow the first order kinetics, i.e. initial content and degradation rate of carotenoids, were determined using NLIN statistical procedure. Marquardt method (iterative curve adjustment procedure) was used for determination of the least sum of squares of the residual associated with the regression model.

Statistical analysis. The experiment was carried out as a randomized complete experiment with three replicates. Statistical analysis of the obtained results was performed using SAS statistical software [37], with the results analyzed as repeated measurements with fixed effect of meal type, storage conditions and their interactions using the MIXED procedure with SP(POW) as the covariance structure for time intervals and Tukey's test to assess the significance of multiple comparisons differences. Mean values and standard error were determined using the LSMEANS procedure, while mean differences were determined using the PDIFF procedure. The threshold for statistical significance was defined as $P < 0.05$.

IV. RESULTS

The initial TC content was higher in meal B (13.63 mg/g DM) than in meal A (10.35 mg/g DM) (Fig.2). These results can be explained by the different composition of carotenoids in petals, leaves and stems [33,38,39]. Namely, leaves and stems contain high amounts of chlorophyll, whereas the petals contain a high amount of the carotenoids xanthophylls (lutein, β-cryptoxanthin, zeaxanthin) which are responsible for the colour of the petals [33,38,39]. Considering that meal A was prepared by milling the whole marigold flowers, the leafy parts of the flower demonstrated diluting effect, and consequently, caused a lower initial TC content in meal B. According to Park et al. (2017) [40], the qualitative and quantitative carotenoid composition of plants depends not only on the proportion of leaves/petals, but also on different biological (cultivar/variety, developmental stage), environmental (agricultural) and post-harvest processes. Moreover, their interactions should be taken into account.

During 77 days of storage, the TC content decreased in both meals (Fig. 2; $P<0.001$). However, the changes in TC content during storage under different conditions differ between meal samples. In meal A, differences between sampling times were determined form 21st day of storage ($P<0.05$). On the 77th day of storage, the highest TC content was determined in samples stored at 25 °C without exposure to light (9.04 mg/g DM), followed by storage at 4 °C (8.86 mg/g DM) and at 25 °C with exposure to light (8.07 mg/g DM). The lowest TC content in meal A was determined

in samples stored at 40 °C (6.09 mg/g DM). Similarly to the presented results, Song et al. (2018) [32] reported the lowest TC in samples of dehydrated pumpkins stored at 40 °C in study investigating the effect of storage temperatures (4, 25 and 40 °C) on TC content after 210 days of storage.

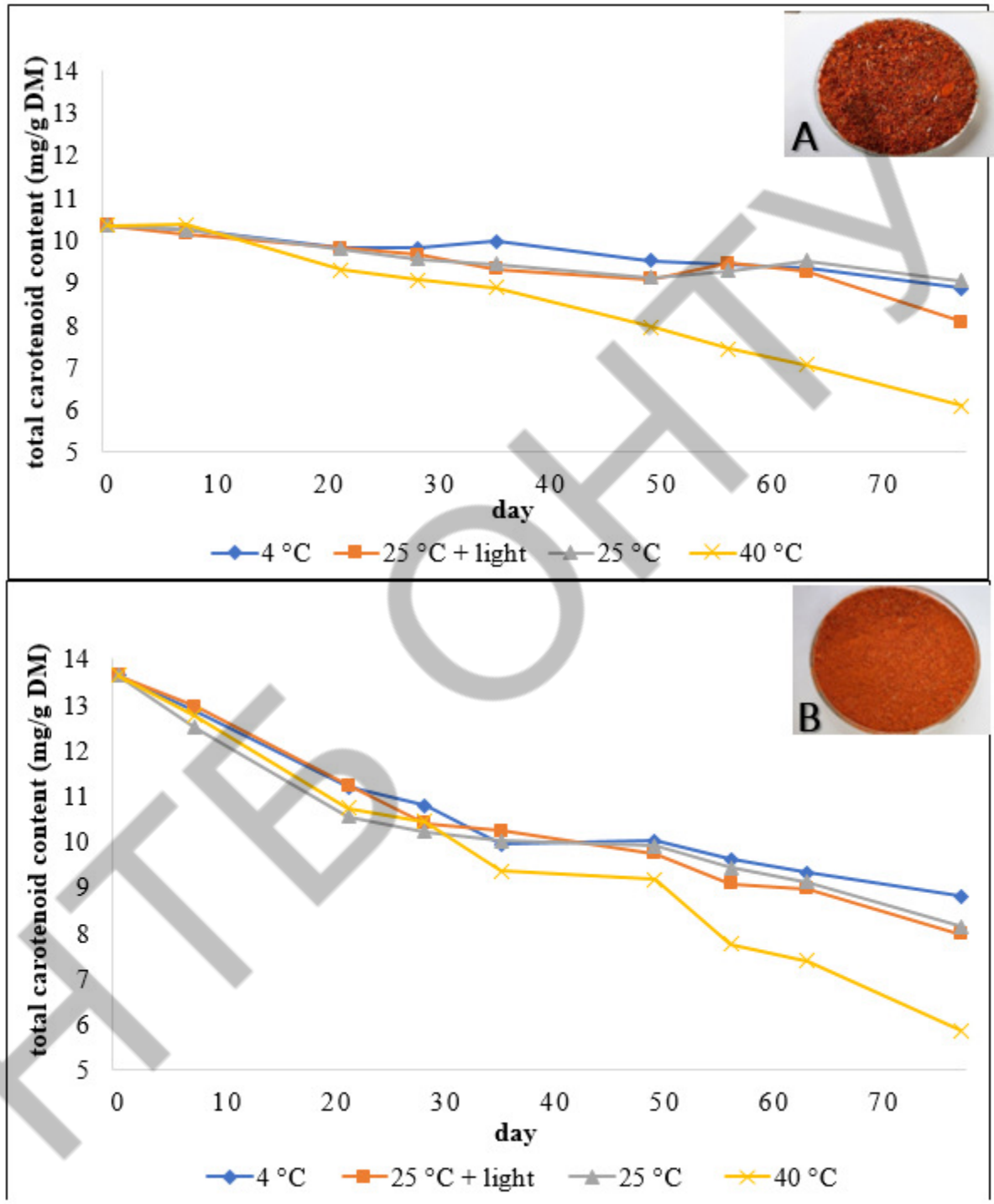

Figure 2. The effect of four storage conditions on the total carotenoid content (mg/g DM) in a meal prepared from whole marigold flowers (A) and in a meal prepared only from marigold petals (B) during 77 days of storage.

In contrast to meal A, changes in TC content in meal B began to decrease immediately after the beggining of storage ($P<0.05$) resulting in a steeper decrease in TC content during the storage period (Fig. 2). After 77 days of storage, the highest TC content was determined in the samples stored at 4 °C (8.81 mg/g DM), while the lowest TC content was found when stored at 40 °C (5.88 mg/g DM). There was no significant difference in TC between meals B stored at 25 °C with exposure to light (7.99 mg/g DM) and without exposure to light (8.15 mg/g DM). Different patterns of decrease in the TC content can be attributed to the absence of the leafy-parts (high chlorophyll content) in meal A, which in some manner reduce the degradation of carotenoids due to their dilution effect in meal B. Furthermore, as can be seen in Fig.1, meal B (prepared by milling only the petals) contained smaller particles that allowed greater exposure to oxygen. Results similar to the decrease in TC content in meal B were obtained in the study by Akshaya et al. (2017) [16]. The authors reported higher TC content in the extract of marigold petals stored at 4 °C compared to extract stored at ambient temperature after 60 days. Due to the polyene chain and terminal groups in their structure [41], carotenoids are, sensitive to oxidation, exposure to light and elevated temperatures [39,41]. These effects lead to the isomerization of carotenoids [39,41], the accumulation of mono- and di-epoxides, carbonyls, alcohols, etc. [39] and consequently to a lower TC content. According to Schweiggert et al. (2006) [41], isomerization can also occur during extraction and saponification of the carotenoids.

In agreement with obsererved differences in TC content between meal types during storage, meal type affected degradation percentage at all timepoints during storage ($P<0.001$; Table 1.). Furthermore, after 21st day of storage, the differences in TC degradation percentage in both meals were detected between storage conditions ($P<0.05$). The degradation precentage of TC was lower in meal A than in meal B ($P<0.001$), regardless of the storage conditions and the duration of storage. More so, a twofold to even threefold higher TC degradation was observed in a meal A at 40 °C compared to the other storage conditions from 49th to 77th day of storage. At the end of the experiment, the highest degradation percentage was determined in samples of meal A stored at 40 °C, followed by storage at 25 °C with exposure to light, and storage at 25 °C without exposure to light and storage at 4 °C, with the two later storage conditions showing no significant difference between them. Likewise, a storage temperature of 40 °C proved to be the most damaging for TC in meal B. Opposite to meal A, a storage temperature of 4 °C proved to be the most effective in protecting TC in meal B.

Table 1. The effect of four storage conditions on the degradation of total carotenoids (%) in a meal prepared from whole marigold flowers (A) and in a meal prepared only from marigold petals (B) during 77 days of storage.

Day of storage	Meal	Storage conditions			
		4 °C	25 °C + light	25 °C	40 °C
		%			
7	A	$1.07^{a,A}$	$2.03^{a,A}$	$0.98^{a,A}$	$0.78^{a,A}$
	B	$5.58^{a,B}$	$4.98^{a,A}$	$8.35^{a,B}$	$6.44^{a,B}$
21	A	$5.27^{a,A}$	$5.19^{a,A}$	$5.43^{a,A}$	$10.29^{b,A}$
	B	$17.86^{ab,B}$	$17.55^{a,B}$	$22.58^{c,B}$	$21.28^{bc,B}$
28	A	$5.2^{a,A}$	$6.84^{ab,A}$	$7.79^{a,A}$	$12.5^{c,A}$
	B	$20.79^{a,B}$	$23.63^{ab,B}$	$25.06^{c,B}$	$23.44^{ab,B}$
35	A	$3.62^{b,A}$	$10.07^{a,A}$	$8.95^{a,A}$	$14.21^{c,A}$
	B	$27.11^{a,B}$	$24.88^{a,B}$	$26.54^{a,B}$	$31.43^{b,B}$
49	A	$8.13^{b,A}$	$12.31^{a,A}$	$11.92^{a,A}$	$23.21^{c,A}$
	B	$26.50^{a,B}$	$28.48^{a,B}$	$27.34^{a,B}$	$32.73^{b,B}$
56	A	$8.88^{a,A}$	$8.75^{a,A}$	$10.3^{a,A}$	$28.24^{b,A}$
	B	$29.42^{b,B}$	$33.41^{a,B}$	$30.81^{ab,B}$	$43.08^{c,B}$
63	A	$9.81^{a,A}$	$10.63^{a,A}$	$8.15^{a,A}$	$31.85^{b,A}$
	B	$31.63^{a,B}$	$34.14^{a,B}$	$33.11^{a,B}$	$45.85^{b,B}$
77	A	$14.39^{b,A}$	$22.08^{a,A}$	$12.72^{b,A}$	$41.15^{c,A}$
	B	$35.35^{b,B}$	$41.41^{a,B}$	$40.20^{a,B}$	$56.95^{c,B}$

^{a,b,c}Values superscribed with the different lowercase letters present statistically significant difference ($p<0.05$) among storage conditions within the same meal type and storage time according to the Tukey's test.

^{A,B}Values superscribed with the different uppercase letters present statistically significant difference ($p<0.05$) among meals within the same storage conditions and storage time according to the Tukey's test.

The rate of degradation of TC in the samples was determined for each month of storage and for the entire storage period. The first approach showed that the highest TC degradation rate was observed in the first month of storage of meal B, regardless of the storage conditions. On the other hand, the rate of degradation of TC in meal B remained constant during all three months of storage, except for the third month of storage at 25 °C with exposure to light and at 40 °C. The highest TC degradation rates were found in both meals almost during all three months for the samples stored at 40 °C.

Table 2. The effect of four storage conditions on the degradation rate (k / day^{-1}) of total carotenoid content in a meal prepared from whole marigold flowers (A) and in a meal prepared only from marigold petals (B) at the end of the first, second and third month of storage.

Month	Meal	Storage conditions			
		4 °C	25 °C + light	25 °C	40 °C
		k / day^{-1}			
1	A	$0.0022^{a,A}$	$0.0025^{a,A}$	$0.0030^{a,A}$	$0.0054^{b,A}$
	B	$0.0087^{a,B}$	$0.0096^{b,B}$	$0.0104^{b,B}$	$0.0102^{b,B}$
2	A	$0.0028^{a,A}$	$0.0010^{a,A}$	$0.0021^{a,A}$	$0.0084^{b,A}$
	B	$0.0012^{a,A}$	$0.0054^{ab,B}$	$0.0025^{ab,A}$	$0.0072^{b,A}$
3	A	$0.0031^{a,A}$	$0.0077^{b,A}$	$0.0016^{a,A}$	$0.0074^{b,A}$
	B	$0.0042^{a,A}$	$0.0063^{ab,A}$	$0.0068^{b,B}$	$0.0133^{c,B}$

^{a,b,c}Values superscribed with the different lowercase letters represent statistically significant difference ($p<0.05$) among storage conditions within the same meal type and month according to the Tukey's test.

^{A,B}Values superscribed with the different uppercase letters represent statistically significant difference ($p<0.05$) among meals within the same storage conditions and month according to the Tukey's test.

The second approach in determination of TC degradation rate was used to evaluate the entire storage period. Meal B showed a higher degradation rate in samples stored under the tested storage conditions compared to meal A, in accordance with the greater decrease in TC content depending on the presence of the leafy-parts and the smaller particles in the meal. The results are consistent with research by Hidalgo and Brandolini (2008) [31], who also found lower TC degradation rates in samples containing leafy carotenoids. For both meals, the highest degradation rates were reported for samples stored at 40 °C. Furthermore, the degradation rates of TC in samples stored at 4 and 25 °C without light exposure were similar for both types of meal, despite the monthly difference in TC degradation rates between these two storage conditions in meal A.

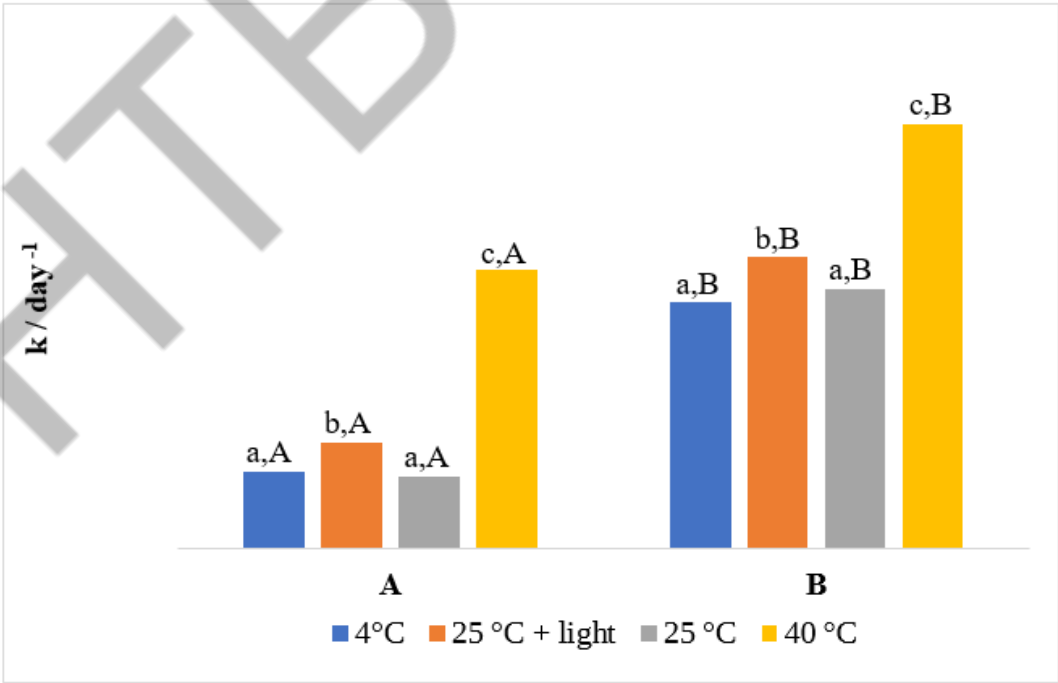

Figure. 3. The effect of four storage conditions on the degradation rate (k /day^{-1}) of total carotenoids in a meal prepared from whole marigold flowers (A) and in a meal prepared only from marigold petals (B) during the whole period of storage (77 days).

^{a,b,c} – Columns superscribed with the different lowercase letters represent statistically significant difference ($p<0.05$) among storage conditions within the same meal type according to the Tukey's test.

^{A,B} - Columns superscribed with the different uppercase letters represent statistically significant difference ($p<0.05$) among meals within the same storage conditions according to the Tukey's test.

V. CONCLUSIONS

Based on the obtained results, it can be concluded that storage conditions (temperature and light exposure) and meal type affect the content and degradation of TC in marigold flowers (*Tagetes erecta* L.). More precisely, higher temperatures (regardless of the meal type) promote the degradation of TC during storage. Consequently, the storage temperature of 40 °C has proven to be the most deleterious. The similarity of TC degradation rates between the two meals stored at 4 °C and 25 °C without light exposure was unexpected, and although recommended storage temperatures for carotenoid sources are close to 0 °C, the results suggest that storage at 25 °C without light exposure could be a cost-effective alternative. In addition, exposure to light has also been proven to be unfavorable to carotenoid retention. Furthermore, the experimental results indicate that the meal type in terms of flower parts used for preparation also affects the TC degradation. Although the initial TC content was higher in the meal prepared only from the petals compared to meal prepared from whole flower, the degradation rates are more pronounced which implies greater sensitivity of this carotenoid source. It can be concluded that, even after 3 months of storage, both types of marigold meals contain sufficient amount of carotenoids and can be used as a supplements in animal nutrition.

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STANDARTIZATION OF RADIATION-TREATED POULTRY MEAT

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Annotation. *Ionizing radiation is recommended for use in the storage of meat, semi-finished products and culinary products from them, fish and other sea products, edible potatoes, onions and other root crops in the spring and summer months, perishable berries and fruits for the duration of their transportation from the manufacturer to the consumer, fruit juice concentrates, etc*

. Further study of the possibility of using ionizing radiation sterilization to extend the shelf life of food products, as well as to ensure quality control and safety of meat and meat products is very relevant for science and practice.

The practical use of ionizing radiation exposure to increase the shelf life of food products is based on their ability to slow down or accelerate the processes of germination or ripening of fruits and vegetables, to fully or partially suppress the vital activity of food spoilage pathogens.

Food processing by ionizing radiation belongs to the so-called high technologies and has been used in Europe and America on an industrial scale for several decades. For these purposes, electron accelerators or special gamma-ray installations with various sources of ionizing radiation are used.

Only certain radiation sources are used for food irradiation: cobalt-60 or caesium-137 isotopes, X-ray installations, electronic accelerators with a maximum energy of no more than 10 MeV. The energy of these radiations is relatively small and does not cause induced radioactivity in any material, including food. None of the chemical changes in the irradiated products is dangerous to health. Irradiation does not affect the nutritional qualities of food. Consumption of irradiated foods does not lead to the formation of abnormal chromosomes, i.e. genetically safe.

Irradiation at internationally recommended dose levels up to 10 kGy eliminates the risk of botulism compared to other "substerilized" technological processes of food processing, such as pasteurization. According to the main indicators, the irradiated products have no signs of poor quality and meet the medical and biological requirements.

Keywords: *standardization, radiation treatment, irradiated material, dose rate, food products, microorganisms, poultry meat.*

I. INTRODUCTION

World industrial experience has proved that the economic efficiency of most organizations is not possible without continuous improvement of their activities to improve the quality of products. At the same time, an important role is played by improving methods for increasing the shelf life of raw materials and food products, taking into account the desire of consumers for biologically safe products. The

presence of a competitive environment in a market economy confirms the importance of quality control problems. Serious competition in countries with developed market economies has led to the development of quality improvement programs. There was a need to develop, among other things, methods of veterinary and sanitary assessment of the quality and safety of raw materials for food production. The role and importance of quality for the formation of the economy of our country are now becoming decisive.

Ionizing radiation is recommended for use in the storage of meat, semi-finished products and culinary products from them, fish and other sea products, edible potatoes, onions and other root crops in the spring and summer months, perishable berries and fruits for the duration of their transportation from the manufacturer to the consumer, fruit juice concentrates, etc.

II. ANALYTICAL REVIEW OF THE LITERATURE

In different countries of the world, the maximum permissible dose of food irradiation varies. In the USA it is 30 kGy, in Belgium and the Netherlands - 10 kGy, in France - 11 kGy. In Russia, this value is not regulated, since radiation treatment of food products has not become widespread in our country due to the lack of regulatory documents.

Further study of the possibility of using ionizing radiation sterilization to extend the shelf life of food products, as well as to ensure quality control and safety of meat and meat products is very relevant for science and practice.

The practical use of ionizing radiation exposure to increase the shelf life of food products is based on their ability to slow down or accelerate the processes of germination or ripening of fruits and vegetables, to fully or partially suppress the vital activity of food spoilage pathogens.

The technological effect of irradiation depends on the conditions of irradiation and the dose of absorbed energy, so: low doses (up to 1 kGy) - inhibit the germination of vegetables and fruits during storage, destroy insects, barn pests;

• medium (1-10 kGy) - harmful to many types of vegetative forms of microbes provide "cold sterilization" of products;

• high (10-50 kGy) - inhibit the vital activity of microbes and spores.

Irradiation is carried out: y - quanta, accelerated electrons, x-ray bremsstrahlung. The main advantage of this method of processing food products is the possibility of a sharp reduction in the amount of various preservatives used in the storage and preparation of food.

The problem of preserving the nutritional properties of the product, as well as the likelihood of the formation of various toxins and mutagens as a result of exposure to ionizing EM radiation at various doses, has been studied in detail for many decades and considered at the level of official international organizations regulating the use of nuclear energy, health and food quality.

When analyzing the technical side of the issue, the problem arises of optimizing the value of the absorbed dose and the treatment regime in terms of preserving the beneficial properties of the product and neutralizing strains of microorganisms. The purpose of processing can be both to extend the shelf life of the product and to prevent the appearance of possible pathogenic viruses. Depending on the type of product and

the purpose of treatment, one or another value of the absorbed dose can be selected. Of course, during the processing there is a partial destruction of some useful components (trace elements, vitamins). And the sale of such products may be associated with the rejection by consumers of the very fact that it came into contact with ionizing radiation. Nevertheless, it should be understood that the varieties of preservatives currently used can definitely provoke the occurrence of serious health disorders. While the radiation treatment method has undergone many years of laboratory research, extensive experience has been accumulated confirming the safety of its industrial application.

The process of radiation sterilization of food consists in the fact that food products, packaged or unpacked, are exposed to carefully controlled levels of ionizing radiation for a specific time to achieve certain desired goals.

Food processing by ionizing radiation belongs to the so-called high technologies and has been used in Europe and America on an industrial scale for several decades. For these purposes, electron accelerators or special gamma-ray installations with various sources of ionizing radiation are used.

Only certain radiation sources are used for food irradiation: cobalt-60 or caesium-137 isotopes, X-ray installations, electronic accelerators with a maximum energy of no more than 10 MeV. The energy of these radiations is relatively small and does not cause induced radioactivity in any material, including food. None of the chemical changes in the irradiated products is dangerous to health. Irradiation does not affect the nutritional qualities of food products. Consumption of irradiated foods does not lead to the formation of abnormal chromosomes, i.e. genetically safe.

Irradiation at internationally recommended dose levels up to 10 kGy eliminates the risk of botulism compared to other "substerilized" technological processes of food processing, such as pasteurization. According to the main indicators, the irradiated products have no signs of poor quality and meet the medical and biological requirements.

The radiation method allows you to use any packaging, significantly prolongs the shelf life, destroys pathogenic microflora. Currently, permission has been obtained from the Ministry of Health of the Republic of Belarus for the practical application of a radiation method for processing a number of food products: egg powder, lactose, various spices, gelatin, poultry meat.

Taking into account the importance of providing the population with high-quality food and the possibilities of the radiation base of the Institute, the Ministry of Health of the Republic of Belarus is developing new standards for microbiological indicators for spices, and is also considering giving the IRFCP the role of a coordinating center for radiation treatment of medical devices and food.

The safety and benefits of food treated with ionizing radiation have been documented. In order to provide accurate scientific information, the International Advisory Group on Food Irradiation decided to publish a series of brochures on this topic in 1991. After these publications, many developments were made in the field of the development of food irradiation technologies. Along with traditional methods of food storage, these technologies are gaining great popularity all over the world. Already in 1905, the first patents for the use of ionizing radiation to kill bacteria in food were issued in the United States and Great Britain. It is known that pork must be

thoroughly cooked or fried, as it may contain a dangerous parasite trichinella. However, this parasite can be destroyed with a minimum dose of radiation. Frog legs can be infected with salmonella, and irradiation in this case is an effective method of disinfection. With the help of irradiation, it is also possible to neutralize salmonella found in chicken eggs without compromising the quality of the product. These diseases threaten human health even in countries with modern food processing systems. According to approximate estimates, the number of cases is several million.

To control these diseases, relatively low doses of radiation are needed, which will neutralize certain food bacteria. For this purpose, in Belgium, France and the Netherlands, significant quantities of frozen seafood are treated with irradiation. The volume of irradiated seasonings and spices worldwide has increased significantly in recent years.

Not all countries currently allow the import of chemically treated fruits. The main importing countries, which include the United States and Japan, have banned the use and import of products treated with certain fumigants that pose a health risk. This is a serious problem for countries whose economies are mainly based on food and agricultural production and receive income from exports. Irradiation treatment is an alternative to chemical treatment for such countries. In addition, the "cold process" of processing (i.e. irradiation) is ideal for preserving the taste and aroma of fruits, herbs and spices, which are often lost during heat treatment. Studies have shown that carbohydrates, proteins and fats undergo little change under irradiation, as well as minerals, vitamins, trace elements. The shelf life of fruits, vegetables, meat, fish and seafood can be significantly increased by a combination of freezing and low doses of radiation, since many rotting bacteria are sensitive to radiation. Irradiation also prevents fruit from overripe.

Products treated with irradiation are specially treated with certain types of radiation energy to destroy pathogenic bacteria and better preservation. In addition to food products, many other materials are treated by irradiation in the production process, for example, cosmetics, bottle caps, medical equipment. Irradiated products cannot become toxic.

Several hundred toxicological experiments were conducted on animals to assess the safety of consumption of irradiated products. These experiments did not show toxic effects, as well as genetic defects as a result of consumption of irradiated products. Can the consumption of irradiated foods cause the appearance of extra chromosomes? No. In the early 1980s, several studies were conducted in China involving 400 volunteers who consumed irradiated food for a period of 7 to 15 weeks. One of the areas of research was the possibility of changes in chromosomes.

In the event of an accident, radiation leakage is impossible, since the source of radiation energy does not produce neutrons that make materials radioactive, so a nuclear "chain reaction" cannot occur on the irradiating equipment. The walls of the irradiation cells through which the products pass, the equipment inside the cell and the processed products cannot be radioactive, radioactivity does not enter the environment. The products themselves never come into direct contact with the source of radiation. The irradiation process is the passage of products through the radiation field at a set speed to control the amount of energy and dose absorbed by the products. Food

products that are exposed to radiation become no more radioactive than luggage undergoing a scan at the airport, or our teeth after an X-ray.

Despite the fact that in 1929 a patent was issued for the use of radiation as a means of preserving or protecting food, it was only shortly after World War II that this method of protecting food received serious consideration. At the same time, the use of radiation is limited, and the full application of this method raises some doubts among microbiologists and other food scientists.

Radiation can be defined as the emission and propagation of energy through a vacuum or through a medium. The main type of radiation that is of interest when preserving food is electromagnetic. Different radiations are separated based on their wavelength, the radiations with the shortest wavelengths are the most destructive for microorganisms. The electromagnetic spectrum can be further divided with respect to the significance of radiation in food preservation as follows: microwave, ultraviolet rays, X-rays (X-rays) and gamma rays. The most interesting radiations used for food preservation are ionizing radiation, radiation with a wavelength of 2000 A or less, for example alpha particles, beta rays, gamma and X rays. Their quanta contain enough energy to ionize molecules in their path. Since they destroy microorganisms without raising the temperature, the process is called cold sterilization.

Types of radiation used to preserve agricultural raw materials and food products.Ultraviolet light (UV) is a strong bactericidal agent with the most effective wavelength equal to approximately 2600 A. It is non-ionizing and is absorbed by proteins and nucleic acids, photochemical changes of which can lead to cell death. The mechanism of bacterial cell death as a result of UV exposure is the occurrence of lethal mutations as a result of action on the nucleic acids of the cell. The poor penetrating abilities of UV light allow it to be used only for surface treatment of the product, where it can catalyze oxidative changes that lead to rancidity, discoloration and other reactions. When using UV light, small amounts of ozone can also be produced on the surface of certain products. UV light is sometimes used to treat the surface of baked cupcakes with candied fruits and nuts and similar products before packaging.

Beta rays can be defined as streams of electrons emitted by radioactive substances. Cathode rays are the same, except that they are emitted by the cathode of the vacuum tube. These rays have poor penetrating power. Among the industrial sources of cathode rays are Van de Graf generators and linear accelerators. The latter are more suitable for food protection. There is some concern about the upper limit of the energy level of cathode rays that can be used without the risk of inducing radioactivity in some food components.

Gamma rays

These are electromagnetic radiation emitted by excited nuclei of elements such as b0Co and 137Cs. This is the cheapest form of radiation for food preservation, because the initial elements are by—products of atomic decay or products of radioactive waste. Gamma rays have excellent penetrating power, unlike beta rays. 60Co has a half-life of approximately 5 years; the half-life of 137Cs is approximately 30 years.

X-rays

These rays occur when heavy metal nuclei are bombarded by accelerated

electrons (cathode rays) in a vacuum tube. Otherwise, they are essentially the same as gamma rays.

III. OBJECT, SUBJECT AND METHODS OF RESEARCH

Initially, the destruction of microorganisms in products by ionizing radiation was described by terminology relating to the destruction of microorganisms by high temperature and chemicals. Although microorganisms can really be destroyed

chemicals, high temperature and radiation, the use of this terminology for products treated with radiation is not entirely correct. Therefore, in 1964, an international group of microbiologists proposed the following terminology for radiation treatment of products [61]. Radappertization is the equivalent of radiation sterilization or "industrial sterility" in the canning industry. Typical exposure levels are 30-40 kGy. The term comes from the surname of the inventor of the method of thermal sterilization of food in sealed containers (canned food) Frenchman Nicolas Francois Appert. In the French transcription, the proper name Appert is at the end. the mute "t", which in the word "appertification" manifests itself and begins to sound.

Radisidation is the equivalent of pasteurization, for example, of milk. Leads to selective suppression of viable non-spore-forming pathogens of most types, except viruses, so that none is detected by any standard methods. Typical radiation doses of this process are 2.5-10 kGy.

Radurization can be considered the equivalent of pasteurization. It contributes to the increased preservation of food quality by significantly reducing the number of viable certain non-spore-forming pathogens by radiation. The usual radiation doses for fresh meat, poultry, seafood, fruits, vegetables and grains of cereals are 0.75-2.5 kg.

Radappertization of any products can be achieved by applying the appropriate dose of radiation under appropriate conditions. Of obvious interest is the effect of this treatment on the endospores and exotoxins of C. botulinum. For type E spores, it has been reported that doses of radiation D of the order of 1.2- 1.7 kGy are required. For spores of type A and B, as Ketre established, the values of D were 2.79 and 2.38 kGr, respectively. Type E spores are the most sensitive to radiation among these three types.

To achieve Y1D processing of meat products at ~30 °C, the following values of kGr are required: for beef and chicken — 41.2-42.7; ham and cod pie — 31.4-31.7; pork — 43.7; beef corned beef and pork sausage — 25.5-26.9. Irradiation treatment of this type does not make products radioactive.

The radiation resistance of C. botulinum spores in liquid nutrient media was studied by Roberts and Ingram, the radiation dose values were significantly lower than for meat products. For three strains of type A, the value of D ranged from 1.0 to 1.4; for two strains of type B— 1.0-1.1; for two strains of type E, 0.8—1.6 and for one strain of type F studied by these authors, the value of D was 2.5 kGy. All strains were irradiated at 18-23 °C, and an exponential mortality rate was used to calculate the D values. Regarding the effect of radiation on each of the five different strains (types A, B, C, E and F) of C. perfringens, it turned out that the values of D in the liquid medium were from 1.5 to 2 kGy. The values of 12D for 8 strains of this organism ranged between 30.4 and 41.4 kGy, depending on the strain and the method of calculating doses of 12D.

The DJO radiation dose values for the Scott A Listeria monocytogenes strain in Mozzarella cheese and ice cream irradiated at 78 °C were 1.4 and 2.0 kGy, respectively. The corresponding calculated values of Y1D were 16.8 and 24.4 kGy. To carry out the radapperization of ice cream and frozen yogurt, 40 kg was enough, but not in the case of Mozzarella or Cheddar cheeses. The dose of radappertization for Bacillus cereus in cheese and ice cream was 40-50 kGr.

Viruses are significantly more resistant to radiation than bacteria. Sullivan et al. found that the radiation dose values of D30 viruses are between 3.9 and 5.3 kGy in a minimal Igla medium with the addition of 2% serum. These 30 viruses included Coxsackie virus, ESNO virus and poliovirus. For five selected viruses exposed to the rays of the radioactive isotope cobalt 60Co in distilled water, the D values ranged from 1.0 to 1.4 kGy. Use of radiation 12D treatment with. botulinum in meat products would lead to the survival of viral particles if they had not previously been destroyed by other methods, such as heating.

The enzymes are also very resistant to radiation, and a dose of 20-60 kGy was found to inactivate only 75% of the proteolytic activity of beef. Blanching at 64 or 70 °C was combined with radiation doses of 45-52 kGy, however, in this case only 95% of the proteolytic activity of beef was inactivated. The main disadvantages of using radiation to process some products are color changes or the formation of flavors. At the same time, those food products that undergo relatively minor changes in color and flavor have received the most attention for industrial radappertization. Bacon is the only product that undergoes slight changes in color and flavor after radappertization. The average scores of the organoleptic bacon after radappertization and the control bacon were close, but the value of the control bacon was slightly higher. Suitable products for irradiation are represented by a wide variety.

When reviewing 539 D values taken from 39 published papers, the most stable of the spore-forming ones were Geobacillns stearothermophilus and Clostridium sporogenes, while the most stable non-spore-forming ones were Enterococcus faeciiim, Alcaligenes spp. and the Moraxella-Acinetobacter group. In general, it follows from the published data that gram-negative bacteria were more sensitive than gram-positive ones.

Causes of the death of microorganisms during irradiation.The effect on microorganisms of various forms of radiant energy, which are electromagnetic vibrations with different wavelengths, manifests itself in different ways. The biological effect of radiation depends on the wavelength. The shorter it is, the more energy it contains, the stronger the effect on the body. The action is based on certain chemical and physical changes occurring in the cells of microorganisms and in the environment. The changes can only be caused by absorbed rays. Therefore, the penetrating power of the rays is of great importance for the effectiveness of irradiation.

Bearing in mind the different resistance of the components of the product to ionizing radiation, their effect is divided into direct and indirect. The first includes chemical changes in food substances or microorganisms under the direct influence of radiation energy, the second — changes as a result of exposure to active radicals formed by direct action on less resistant substances. In food products, the proportion of changes caused by indirect action is about 80%.

When irradiating food products containing in most cases a lot of moisture, the indirect effect of ionizing radiation prevails, due to the appearance of active particles as a result of changes (radiolysis) of water. Direct action is typical for dry foods and fats.

The depth of changes under the influence of ionizing radiation increases with increasing radiation energy and radiation dose.

Under the action of ionizing radiation on water, ionized molecules and active radicals are formed.

Thus, as a result of radiolysis of water, free active radicals H and OH appear, which have a high reactivity. These radicals can react with each other, forming active molecules, or interact with other components of the product, causing their undesirable changes. In the presence of oxygen, the formation of an active hydroperoxide radical is possible.

Radioactive radiation, a-rays, (3-rays (high-speed electrons) and y-rays (short-wave X-rays) have high energy, and therefore are chemically and biologically extremely active.

The peculiarity of radioactive radiation is their ability to cause ionization of atoms and molecules, which is accompanied by the destruction of molecular structures.

Microorganisms are significantly more resistant to radiation than higher organisms. The lethal dose for them is hundreds and thousands of times higher than for animals and plants.

The effectiveness of ionizing radiation on microorganisms depends on the absorbed radiation dose and many other factors. Very small doses activate some vital processes of microorganisms, affecting their enzyme systems. They cause hereditary changes in the properties of microbes, leading to the appearance of mutations. With an increase in the radiation dose, the metabolism is disrupted more significantly, various kinds of pathological changes in cells (radiation sickness) are observed, which can lead to their death. At a dose lower than lethal, normal vital activity of irradiated cells can be restored.

The radiation resistance of various types and even strains of microorganisms varies widely. The most radio-resistant microorganisms with increased carbohydrazic and proteolytic activity, containing more magnesium and calcium in the cells, as well as having a high level of protective metabolic reactions. E. coli, proteus, and many bacteria of the genus Pseudomonas are sensitive to radiation — common pathogens of spoilage of meat and fish products. Micrococci are characterized by increased resistance. Bacterial and fungal spores are very radio-resistant. High radiation resistance of viruses; in some, it surpasses even the resistance of bacterial spores.

At the same absorbed dose, the radio frequency of microorganisms of the same species varies depending on the age of cells, the composition of the medium, temperature, and also the dose rate — the radiation dose per unit of time.

The radiation source for the radiation treatment of products is mainly the radioactive isotopes b0Co and 137Cs.

When processing food, the radiobiological effect depends on the composition of the microflora, its abundance, chemical composition and aggregate state of the product, absorbed dose and dose rate.

According to the decision of the Joint Committee of Experts, a number of International Organizations (FAO, IAEA, WHO2), irradiated food products should not contain pathogenic microorganisms and microbial toxins, as well as toxic substances that can be formed as a result of irradiation.

International organizations have approved a list of food products that are allowed to be subjected to radiation treatment. In our country, in each individual case, a permit is issued by the health authorities.

In necessary cases, to increase the effect, irradiation can be combined with other exposure factors (cold, heating, chemical preservatives, etc.).

In our country, the current radiation treatment of products is hindered by the lack of a sufficient number of stationary and advanced installations, and there are no specialists with the necessary qualifications to manage this new technology of food storage. In addition, it is impossible not to take into account a certain consumer alertness to irradiated food.

Trends in the development of radiation treatment methods.In recent years, a new safe sterilization technology has appeared — electron beam. Unlike the methods of sterilization by gamma radiation and ethylene oxide, electron radiation does not use radioactive isotopes. Commercial application of the electron beam method was limited by two factors: the cost and lack of options for packaging materials, the adaptation of which would be scientifically confirmed. George Sadler, professor at the National Center for Food Safety Technology, Illinois, notes: "Electron beam radiation systems appeared back in the 50s, but until recently their operation was very expensive.

Note that electron beam (EL) radiation does not involve deep penetration into the thickness of the product, as does gamma radiation. EL penetrates into the product to a depth of 7.5 cm from the surface.

The effect of EL radiation is limited to a few seconds, unlike many hours of exposure to gamma radiation on the product. The short duration of exposure to accelerated electrons reduces the possible effects of oxidation of the product, minimizing disturbances in the structure of both the product and the packaging material. Most importantly, EL- (EVA). Most other packaging films were approved and tested in the 1960s only for gamma radiation. Over time and the in-depth development of technologies, the cost of electronic sterilization has decreased to a completely acceptable level, arousing interest from the food and packaging industry. Now it's time to expand the list of packaging options for E-sterilization."

Professor Sadler heads a working group consisting of representatives of 20 companies, mainly large suppliers and processors of plastics, such as KaKDuPont, Dow, Cryovac, American National Can, trying to get permission from the FDA to use an expanded range of packaging films and some structures based on semi-rigid and rigid plastics. The group tested and developed documentation for the use of materials such as ethylvinyl alcohol (EVON), nylons, all iogumers. "The interest in EL radiation is dictated primarily by the safety considerations of this sterilization method. We predict that fresh and processed meat, chicken will be the first objects of application of this technology.

Several issues remain unresolved, especially concerning composite multilayer packaging materials and how they will be affected by electron beam radiation. It is

assumed that about 80-90% of single-use medical plastic packages will be compatible with E—processing," says George Sadler.

Experts tend to believe that "if gamma radiation was the first step towards the application of this kind of technology, EL radiation is the second, then the time will soon come to use X-rays as a radiation source. The latest technology combines the speed of the electron beam method and the deep penetration of gamma radiation."

In 1981, the United Nations Food and Agriculture Organization (FAO), the International Atomic Energy Agency (IAEA) and the WHO Expert Committee on Food Irradiation found that foods irradiated with doses up to an average of 10.0 kGy were absolutely safe. At least 40 countries have approved the irradiation of one or more foods, and 29 countries are using food irradiation on an industrial scale. For the control of salmonella in animal feed, in 1995, irradiation with doses of 2-25 kGy was approved in the USA; in 1997, irradiation with a dose of 4.5 kGy was approved for chilled raw materials and a dose of 7.5 kGy for frozen raw beef.

In our country, the current radiation treatment of products is hindered by the lack of a sufficient number of stationary and mobile installations, as well as specialists with the necessary qualifications to manage this new technology of food storage. In addition, it is impossible not to take into account a certain consumer alertness to irradiated food.

Ionizing radiation has a strong bactericidal effect, providing, with sufficient dosage, complete sterilization in a very short time (tens of seconds). Among the radioactive radiations, gamma rays with high rigidity and, consequently, greater penetrating power (about 10 cm) are of practical importance. Radioactive isotopes of cobalt (cobalt-60), caesium (caesium-137) and other elements, as well as radioactive waste from nuclear reactors can be used as sources of gamma rays. The latter source is cheaper, but it is more difficult to use it, since you have to deal with a large number of radioactive isotopes having different radiation spectra.

The nature of the effect of ionizing radiation on the product depends on the radiation energy and the radiation dose (the amount of radiation absorbed by the substance). To estimate the dose relative to this irradiated substance, it is customary to use units equivalent to X-rays. Currently, the radiation dose is more often expressed in non—relative units - rad (1 rad is equal to 100 erg / g).

The same radiation dose can be achieved with a high radiation energy and a short irradiation time, or with a low radiation energy and a long irradiation time. But the effect of the action will not be equivalent, since the nature of the changes in the substance depends on the radiation energy.

Compared with other methods of protecting products from spoilage, ionizing radiation has the following advantages:

a) minor general chemical changes of the product;

b) a slight rise in the temperature of the irradiated product (within a few degrees);

c) processing of products in a short time to the desired depth (from surface exposure to a significant thickness of the irradiated layer);

d) the possibility of organizing continuous-flow processing;

e) the use of any kind of sealed packaging.

Along with this, there are also significant drawbacks: the occurrence of such chemical changes that can worsen the taste, smell, consistency, the danger of the

formation of harmful compounds during and after irradiation; the development of enzymatic processes during storage.

It has not yet been possible to prevent undesirable changes in full, so the widespread use of ionizing radiation on an industrial scale is delayed.

Ionizing radiation is recommended for use in the storage of meat, semi-finished products and culinary products from them, fish and other sea products, edible potatoes, onions and other root crops in the spring and summer months, perishable berries and fruits for the duration of their transportation from the manufacturer to the consumer, fruit juice concentrates, etc.

Radiation technology of processing and storage of products is based on the suppression of microbial contamination (radurization) or radiation sterilization (radappertization).

The conducted studies have confirmed the prospects of the method of their disinfection using gamma radiation and accelerated electrons. However, at the same time, there are some biochemical changes in products with partial loss of vitamins and changes in organoleptic properties.

In different countries of the world, the maximum permissible dose of food irradiation varies. In the USA it is 30 kGr, in Belgium and the Netherlands - 10 kGr, in France - 11 kGr. In Russia, this value is not regulated, since radiation treatment of food products has not become widespread in our country due to the lack of regulatory documents.

The use of ionizing radiation opens up completely new possibilities for the preservation of food products, since there is no significant increase in temperature. This provision makes it possible to solve packaging issues in a new way, using polymer materials for meat products.

However, the problem with the use of ionizing radiation is the protection of the product itself from the influence of those doses of radiation that are needed to destroy microorganisms.

The scientific work was carried out at the department of "BiCPP" of JSC "ATU" in the period from 2021-2023 and in April 2022.

The meat of broiler chickens of the "Broiler 6" cross, taken immediately after slaughter at the poultry farm, served as the material for research. Processing of meat with gamma radiation was carried out in the RSE at the Institute of Nuclear Physics of the Ministry of Energy of the Republic of Kazakhstan at the ILU-10 accelerator.

Pic. 1. ARM of the operator ILU-10

Pic. 2. The resonator of the ILU-10 accelerator.

Meat samples before gamma radiation treatment were packed in plastic bags with a thickness of 20 to 45 microns. Irradiation of samples was carried out on a powerful gamma installation K - 120000 with a Co60 radiation source according to GOST R ISO/ASTM 51204:2004 "Guidelines for dosimetry in the processing of food with gamma radiation". The power of the absorbed radiation dose was: 2 kGy, 4 kGy, 6 kGy and 8 kGy.

The objects for laboratory research were samples of femoral and pectoral muscles of broiler chickens.

Method of processing broiler chicken meat by gamma radiation. Irradiation of samples was carried out on a powerful gamma installation K - 120000 with a Co60 radiation source according to GOST R ISO/ASTM 51204:2004 "Guidelines for dosimetry in the processing of food with gamma radiation". The power of the absorbed radiation dose was: 2 kGr, 4 kGr, 6 kGr and 8 kGr.

The main purpose of irradiation is to control (reduce the number of) pathogenic bacteria in fresh or frozen red meat and poultry meat in order to ensure the safety of these foods for consumption. Irradiation significantly reduces the number of vegetative pathogenic bacteria, such as Campylobacter, Escherichia coli, Listeria, Salmonella, Staphylococcus aureus, or Yersinia enterocolitica, and others if they are identified and determined in accordance with GOST 21237, GOST R 50396.7, GOST R 50454.

Irradiation also inactivates parasites such as Trichinella spiralis and Toxoplasma gondii.

Irradiation prolongs the shelf life of fresh red meat and poultry meat by reducing the number of viable, vegetative bacteria that cause spoilage, for example, various types of pseudomonas (Pseudomonas).

Radiation exposure of fresh and frozen red meat and poultry products is a critical control point (CCT-SSR) in the risk analysis system of critical control points (HACCP) according to GOST R 51705.1. This system serves as an important means of controlling residual risks caused by pathogenic microorganisms before the product reaches the consumer.

Requirements for criteria for evaluating the effectiveness of irradiation

The requirement for the appointment of radiation for the control of pathogenic bacteria should be based on the criteria of an experimentally determined number of

pathogenic bacteria that can lead to contamination of products, their type and susceptibility to them of this consumer. The introduction of quantitative criteria determining the use of irradiation for not exceeding the permissible levels of contamination or the complete absence of possible pathogenic bacteria, which is established by sanitary standards for meat and poultry meat, is the most acceptable factor for the purpose of radiation treatment.

The requirement for the appointment of radiation for the inactivation of parasites should be based on the criteria for the suppression of parasites in raw, irradiated products, so that they are usually non-infectious and harmless. It is not necessary that the parasites were killed during irradiation.

The requirement for the purpose of irradiation to extend the shelf life should be based on the criteria for determining the number of microorganisms by sowing on Petri dishes under conditions corresponding to the storage conditions: at a certain time, temperature and environmental parameters. It should be taken into account that if the requirements of sanitary regulations, technical specifications for the product are known, for example, according to GOST 779, GOST 4814, GOST 12512, GOST R 52702, GOST R 52601, GOST R 52675 or both, then the reduction in the number of bacteria cannot be indicated as the only one or the final criterion. Thus, the requirement for the final product regarding the determination of the number of microorganisms by sowing on Petri dishes, as a criterion for the use of radiation, must be established by the client (customer).

If these criteria are not met, it is necessary to pay attention to the regulated process (see 8.1) and, if necessary, to restore the rules of production organization and product quality control (GMP). Risk analysis and critical control points (HACCP) according to GOST R 51705.1 or another similar process control system should be applied to the entire processing process and transport chain. Any point in the chain where a dangerous or critical situation occurs can be controlled and regulated using this system so that a dangerous and harmful product is prevented from reaching the consumer. See GOST R ISO 22000, provisions of the Codex Alimentarius.

The implementation of a process control system for evaluating the effectiveness of radiation treatment should include bacteriological examination of products before and immediately after irradiation, the use of time and temperature indicators of the entire process chain, and testing the integrity of packaging. Bacteriological testing should reveal a significant reduction in the number of certain bacteria compared to their number in non-irradiated products. Temperature control should warn the operators of any product about a violation that may lead to an increase in the number of bacteria after irradiation.

Methods for determining organoleptic and commodity indicators of meat quality of broiler chickens. Sampling and organoleptic examination of meat was carried out according to GOST 20235-74, 7702.0-74.

Organoleptic studies (color, smell, taste, consistency, cooking sample with broth evaluation) were carried out with the participation of volunteers in the number of 10 people. The organoleptic parameters of broth and boiled meat were evaluated according to a 9-point system (VNIIMP method), which includes determining the quality level of each indicator by its intensity in this product and according to GOST

9959-91, the transparency and aroma of the broth were determined according to GOST 7269-79. The well-being of each taster was determined independently for five days.

When studying commodity indicators of carcasses of broiler chickens, the appearance of carcasses, their fatness, weight, as well as the morphological composition of broiler tissues (the ratio and yield of white and red meat, internal fat, skin, bones) were compared, according to the method of studying slaughter yields and meat of VNIIMP.

Physico-chemical methods of research. Methods recommended by GOST 28825-90 Poultry meat were used for the physico-chemical study of broiler chicken meat. Acceptance; GOST 7702.1-74, 23392-78, 23042-86; "Rules of veterinary inspection of slaughter animals and veterinary and sanitary examination of meat and meat products". At the same time, the following were determined: the pH of white and red meat, peroxidase, the content of primary protein breakdown products in the broth (reaction with copper sulfate), the content of ammonia and ammonium salts (with Nessler reagent), the amount of volatile fatty acids and the acid number of fat — a day after the slaughter of poultry by existing known methods, as well as the intensity of coloring and water-binding (water-retaining) the ability of white and red meat.

Determination of the pH of meat. The determination was carried out by the potentiometric method on the universal ionomer EV-74. The pH of the meat was determined in an aqueous extract prepared in a ratio of 1:10. The mixture was infused for 30 minutes, stirring occasionally, and filtered through a paper filter. After checking the device with distilled water, a test hood was placed in a vessel for electrodes, the electrodes were immersed and the readings of the device were counted on a scale.

Reaction to peroxidase. 2 ml of extract made from minced meat and distilled water in a ratio of 1:4 was added to the test tube, 5 drops of 0.2% alcohol solution of benzidine were added, the contents of the test tube were shaken, after which two drops of 1% hydrogen peroxide solution were added. The meat was considered fresh if the hood acquired a blue-green color, passing within 1-2 minutes. in brown-brown (positive reaction). The meat was considered stale if the extract either did not acquire a specific blue-green color, or a brownish-brown (negative reaction) immediately appeared.

IV. RESULTS OF THE WORK

The meat of broiler chickens of the "Broiler 6" cross, taken immediately after slaughter at the poultry farm, served as the material for research. The processing of meat with gamma radiation was carried out at the All-Russian Research Institute of Physical, Technical and Radio Measurements. Meat samples before gamma radiation treatment were packed in plastic bags with a thickness of 20 to 45 microns. Irradiation of samples was carried out on a powerful gamma installation K - 120000 with a Co60 radiation source according to GOST R ISO/ASTM 51204:2004 "Guidelines for dosimetry in the processing of food with gamma radiation".

It is established that the requirement for the purpose of irradiation to extend the shelf life should be based on the criteria for determining the number of microorganisms by sowing on Petri dishes under conditions corresponding to the storage conditions: at a certain time, temperature and environmental parameters. It is also taken into account

that if the requirements of sanitary regulations, technical specifications for the product are known, for example, according to GOST 779, GOST 4814, GOST 12512, GOST R 52702, GOST R 52601, GOST R 52675 or both, then the reduction in the number of bacteria cannot be specified as the sole or final criterion. Thus, the requirement for the final product regarding the determination of the number of microorganisms by sowing on Petri dishes, as a criterion for the use of radiation, must be established by the client (customer).

In case of non-compliance with these criteria, it is necessary to pay attention to the regulated process (see 8.1 of the standard) and, if necessary, to restore the rules of production organization and product quality control (GMP). Risk analysis and Critical control points (HACCP) according to GOST R ISO 22000 or another similar process control system should be applied to the entire processing process and transport chain. Any point in the chain where a dangerous or critical situation occurs can be controlled and regulated using this system so as to minimize the likelihood of a dangerous and harmful product reaching the consumer. See GOST R ISO 22000, provisions of the Codex Alimentarius.

Requirements for processing products before irradiation. Having studied the specialized literature and relevant regulatory documents, we found out that most researchers provide for the treatment of meat and poultry meat by irradiation only in an environment that does not increase the risk of physical, chemical or biological contamination. Reducing the risk of infection with microbes and their growth is ensured by the implementation of the provisions of the relevant standards for the organization of good manufacturing practices and product quality control (GMP): CAC Recommended International Code of Regulations CAC/RCP1 and GOST R 51705.1.4.

Package integrity. The integrity of the package is checked visually by inspection of the product packaging. It is necessary to make sure that there are no signs of its damage or violation. In addition, organoleptic sensory checks of the product must be performed according to GOST 7269, GOST R 51944 or according to the corresponding technical specifications. After the inspection, the absence of a liquid leak or an odor indicating the spoilage of the product was recorded.

Storage of test samples before irradiation. It should be noted that storing the product in the refrigerator for a long time is a violation of GMP, since such storage can lead to increased bacterial growth and undesirable product changes. For frozen red meat and poultry, it is always necessary to maintain the temperature of the product no higher than -18 ° C. The relatively short storage time of the product in frozen form before irradiation is not critical under normal commercial conditions.

However, freezing does not provide the product with an infinite shelf life without loss of quality, so the storage period before irradiation should be minimal.

It is important to ensure separate storage of products before and after irradiation, since visually distinguish products that have been irradiated from non-irradiated ones. Therefore, it is very important that appropriate facilities are provided at the irradiation facility to allow the processed products to be stored separately from the untreated ones, such as physical barriers or clearly delineated storage areas with appropriate labeling.

Product packaging and loading configuration requirements

Packaging of the product before irradiation is one of the means of preventing

infection after irradiation.

3.1.3. Radiation requirements

Generating sources: X-rays from artificial sources with an energy less than or equal to 5 MeV: a stream of accelerated electrons from an artificial source with an energy less than or equal to 10 MeV.

Requirements for the absorbed dose

Based on international requirements, the following conditions were adhered to: it is necessary to choose the lowest dose necessary to ensure the desired effect (e.g., reducing the number of microbes, suppressing the activity of pathogens), and the highest dose that does not adversely affect the quality of the product due to the formation of an extraneous taste, smell and color change.

The above-mentioned restrictions on absorbed doses may be additionally established by federal supervisory authorities for a specific applied technology for processing specific types of products.

According to the results of the study, in order to achieve the same effect in the case of frozen products, a higher minimum dose was required than for a product irradiated in a chilled form, since the resistance of bacteria to radiation damage is higher at a lower freezing temperature.

Dosimetry requirements during the irradiation process

Dosimetric control is one of the main components of the overall quality assurance program to comply with good manufacturing practices used in the production of safe and healthy food. The Codex Alimentarius documents define the value of dosimetry to ensure the correctness of irradiation. Dosimetry must be performed in accordance with the requirements of ISO/ASTM 51204 or ISO/ASTM 51431, and ASTM E2303.

Product temperature requirements:

Before the start of irradiation, it is necessary to measure and record the temperature of the product at the entrance of the irradiator chamber, after the end of irradiation - at the exit of the chamber, in order to confirm its compliance with the requirements of the technological regulations of the process

treatments at this irradiation facility. If the temperature in the irradiation area and the time required to achieve the desired absorbed dose lead to an increase in temperature beyond the established limits, the process conditions are considered unfulfilled. It is necessary to make appropriate changes to the process, which may include thermal insulation of the treatment batch or cooling of the irradiation zone. If the product is isolated during irradiation, repeated characterization of the absorbed dose distribution may be required for the application of the insulating material.

Requirements for handling and storage of products after irradiation. Labeling of irradiated products should be carried out in order to create a choice for consumers and food enterprises between irradiated and non-irradiated products. Labeling will allow to identify the product as irradiated and inform the consumer about the purpose and benefits of processing, as well as about the requirements for handling and storage of the product. In international practice, national and international regulations and recommendations for labeling products have been adopted. The necessary information must also be specified in accordance with GOST R 51074. An increasing number of

countries accept the "Radura" mark, which has received international recognition, as a marking. Such a sign may (should) be accompanied by a mark-statement, such as "Treated by radiation" or "Treated by irradiation".

After irradiation, it is necessary to count the products by counting the irradiated containers. Comparison of this information with the amount provided before irradiation ensures verification that all products received have been irradiated or otherwise accounted for and registered.

The objects for laboratory research were samples of femoral and pectoral muscles of broiler chickens.

Study of organoleptic parameters of broiler chicken meat. Thanks to the organoleptic evaluation, it is possible to quickly obtain information about the indicators of products that determine the color, taste, aroma, consistency, juiciness and some other properties necessary for scientifically based recommendations for the use of poultry meat.

Determination of physico-chemical parameters of broiler chicken meat. Physico-chemical indicators of meat indicate its good quality and safety for consumers. They give an assessment of its ability to long-term storage in chilled and frozen form.

The effectiveness of the effect of radioactive radiation on the ILU-10 electron accelerator on the reduction of microbiological contamination was confirmed. The effectiveness of radiation against pathogens is mainly due to the formation of hydrogen peroxide, which occurs as a result of the formation of free radicals during irradiation. Hydrogen peroxide acts as a powerful antimicrobial agent and can eventually lead to the formation of long-lived hypochlorite, which is very toxic to pathogens. The results of this study show that radiation doses of 2-8 kGy - 254 MJ/cm2 were effective for killing bacteria in boneless chicken breast fillets.

Pic. 3. Irradiation of poultry meat samples.

Treatment of ILU-10 at 2-8 kGy reduced the number of coliforms, E. coli, aerobic bacteria and psychrotrophs on microbiological parameters of poultry meat at temperatures from 0°C to +2 °C compared with the control group that did not receive radiation (Table 1).

Table 1. Microbiological parameters of broiler chicken meat after treatment with various types and storage at a temperature from 0 ° C to +2 ° C

Name of the indicators to be determined	**Hygienic standard**	**Test results**	
		on an electronic accelerator	
		2 kGy	**8 kGy**
After slaughter			
QMAFAnM	no more $1,0x10^4$CFU/g	1,9-2,0 $x10^2$ CFU/g	5,7-5,5$x10^2$ CFU/g
Escherichia coli group bacteria – CGB coli-forms	not allowed in 0,1; 0,01 г	Not detected	Not detected
Pathogenic, Including salmonella	not allowed in 25,0 г	Not detected	Not detected
L. monocytogenes	not allowed in 25 г	Not detected	Not detected
fungus	No more 10 CFU/g	Less than 10 CFU/g	Less than 10 CFU/g
5 days			
QMAFAnM	no more 1,0 $x10^4$CFU/g	4,2-5,2 $x10^2$ CFU/g	6,8-7,2$x10^2$ CFU/g
Escherichia coli group bacteria – CGB coli-forms	not allowed in 0,1; 0,01 г	Not detected	Not detected
Pathogenic, including salmonella	not allowed in 25,0 г	Not detected	Not detected
L. monocytogenes	not allowed in 25 г	Not detected	Not detected
fungus	No more 10 CFU/g	Less than 10 CFU/g	Less than 10 CFU/g
14 days			
QMAFAnM	no more $1,0x10^4$CFU/g	4,5-5,5$x10^3$ CFU/g	7,7-8,2 $x10^3$ CFU/g
Escherichia coli group bacteria – CGB coli-forms	not allowed in 0,1; 0,01 г	Not detected	Not detected
Pathogenic, including salmonella	not allowed in 25,0 г	Not detected	Not detected
L. monocytogenes	not allowed in 25 г	Not detected	Not detected
fungus	No more 10 CFU/g	Less than 10 CFU/g	Less than 10 CFU/g

After 5 days, the index of QMAFAnM in the meat of the control group increased 2.2 times, and after 14 days it averaged 1.1-2.6 x 104 CFU/g, which exceeded the value of hygienic standards by 2 times.

Treatment of ILU-10 at 2-8 kGy reduced the number of coliforms, E. coli, aerobic bacteria and psychrotrophs on microbiological parameters of poultry meat at a temperature of -18 °C compared with the control group that did not receive radiation (Table 2).

Table 2. Microbiological indicators of broiler chicken meat after treatment with various types and storage at a temperature of -18 ° C

Name of the indicators to be determined	Hygienic standard	Test results	
		on an electronic accelerator	
		2 kGy	8 kGy
45 days			
QMAFAnM	no more 1,0 x10^4CFU/g	1,3-1,6 x10^2 CFU/g	4,5-4,8 x10^1 CFU/g
Escherichia coli group bacteria – CGB coli-forms	not allowed in 0,1; 0,01 g	Not detected	Not detected
Pathogenic, including salmonella	not allowed in 25,0 г	Not detected	Not detected
L. monocytogenes	not allowed in 25 g	Not detected	Not detected
fungus	no more 10 CFU/g	Less than 10 CFU/g	Less than 10 CFU/g
90 days			
QMAFAnM	no more 1,0 x10^4CFU/g	2,2-5,5 x10^2 CFU/g	5,6-7,6x10^2 CFU/g
Escherichia coli group bacteria – CGB coli-forms	not allowed in 0,1; 0,01 g	Not detected	Not detected
Pathogenic, including salmonella	not allowed in 25,0 g	Not detected	Not detected
L. monocytogenes	not allowed in 25 g	Not detected	Not detected
fungus	no more 10 CFU/g	Less than 10 CFU/g	Less than 10 CFU/g
135 days			
QMAFAnM	no more 1,0 x10^4CFU/g	2,5-3,1 x10^2 CFU/g	5,4-6,5 x10^1 CFU/g
Escherichia coli group bacteria – CGB coli-forms	not allowed in 0,1; 0,01 g	Not detected	Not detected
Pathogenic, including salmonella	not allowed in 25,0 g	Not detected	Not detected
L. monocytogenes	not allowed in 25 g	Not detected	Not detected
fungus	No more 10 CFU/g	Less than 10 CFU/g	Less than 10 CFU/g

The dose of radiation of ILU-10 rays of only 2 kGy leads to a decrease in the total number of aerobic organisms by 2-3 times, but does not lead to the complete destruction of organisms in the breasts and thighs of broilers. The radiation dose of 8 kg is effective for reducing the number of enterobacteria, as well as coliform and the total number of mesophilic bacteria in spices. There was a decrease in microbiological indicators by 2-3 times

In our studies, the pH value of meat and other chemical parameters were determined a day after slaughter and sterilization, as well as at various storage periods. From the data presented in Figure 6, it can be seen that the pH value in red and white muscles 5 and 14

days after storage at a temperature from 0 ° C to +2 °With and treatment with doses of 2, 6 and 8 kGr differs slightly.

In the white and red muscles of the control group, after 5 days of storage, the pH index was 5.26-5.35%, when irradiated with a dose of 2 kGr -5.15-5.24%), when irradiated with a dose of 6 kGr - 5.09-5.18% and at 8 kGr - 5.04-5.08%. Accordingly, when storing broiler meat after 14 days, the pH was less than the control by an average of 0.21; 0.27 and 0.31%.

V. CONCLUSION

The table also shows that processing on an electronic accelerator with doses from 2-8 kGy leads to a decrease in microorganisms.

Based on the results of this study, treatment with ILU-10 is an effective means of destroying bacteria from poultry meat even at a minimum dose of 2 kg. The radiation dose of 2 kg was also effective for improving the color of breast fillet, which gives reason to use it for food purposes without restriction.

1. Broiler chicken meat treated with ionizing radiation at a dose of 2 and 6 kGy and stored at a temperature from 0 ° C to +2 ° C has a KMAFAnM index from 4.7-5.0x101 CFU/g to 2.6-4.2x103 CFU/g, and frozen meat at a temperature of -18 °C - from 4.4-4.5 x 101 CFU/g to 1.2-1.4x2 CFU/g, respectively, which meets the requirements of SanPiN 2.3.2.1078-01.

2. The organoleptic parameters of broiler chicken meat treated with ionizing radiation doses of 2 and 6 kGy do not differ from the meat of control chickens. The surface of the carcasses of the experimental groups has a whitish-pink hue, the muscles are elastic, moderate humidity on the section, the internal fat is yellowish. The meat of broiler chickens irradiated with 8 kGr had a pronounced odor deviation due to the rancidity of fat.

3. The pH value of broiler meat of the control group after 5 days of storage (0-2 ° C) was - 5.26-5.35%, and meat treated with ionizing radiation doses of 2 kGr, 6 kGr and 8 kGr decreases in pH: after 5 days - an average of 1.3 times; after 1.5 and 6 months - 1.5 times, respectively. When storing meat at a temperature of - 18 ° C after 1.5 and 6 months, the pH value decreases by 1.5 -1.8 times, respectively, while the acid number of fat increases during storage (0-2 °C) of meat for 60 days in the control group by 5.9 times, and when irradiated with doses of 2, 6 and 8 kGy - in two; 2, and 3.2 times, respectively. And when meat is frozen (- 18 ° C) and stored for 6 months, it increases in the control group by 6.9 times, when sterilized with doses of 2; 6 and 8 kg - by 1.9; 1.8 and 2.9 times.

4. The amount of moisture in the meat of broiler chickens when stored from 0-2 ° C after 5 and 14 days decreases when irradiated with a dose of 8 kGy - in white muscles by 6.13 and 12.35%, in red muscles - by 7.05 and 13.49%, respectively. Meat exposed to radiation, when frozen (-18 ° C) and stored for 1.5 and 6 months, the moisture index decreases during sterilization with an irradiation dose of 8 kGy by 15.1 and 15.9% and in red muscles - by 13.1 and 14.9%, respectively.

The amount of meat protein when irradiated with a dose of 2 kGr decreases by an average of 6.5%; at a dose of 6 kGr - by 8.4%; at a dose of 8 kGr - by 13.7%, and when frozen and irradiated with a dose of 2 kGr after 6 months - by 4.9%; at a dose of

6 kGr - by 6.6% and at a dose of 8 kGr - by 6.9%.

The fat content under the same processing conditions decreases when stored at 2 ° C - by 0.59; 1.05 and 1.6, respectively, and when frozen - by 1.5; 2.6 and 3.2%, respectively. The mass fraction of dry substances decreases during storage (2 ° C) by 2.3; 4.03 and 7.7%, and during freezing - by 4.1; 4.8 and 6.9%, respectively. The amount of ash during storage at 2 ° C increases - by 0.77; 0.76 and 0.72% and during freezing - by 0.015; 0.065 and 0.12%, respectively.

5. The amount of interchangeable amino acids in meat irradiated with a dose of bkGr and 8 kGr decreases in red and white muscles due to a decrease in the amount of tyrosine by an average of 0.65 and 1.025% and cysteine by 0.93 and 1.97%, respectively. The number of interchangeable amino acids decreases due to a decrease in methionine at an irradiation dose of 6 kGy - by 0.91% and at an irradiation dose of 8 kGy - by 1.13%.

6. Microstructural parameters of red and white muscles treated with ionizing radiation had no pronounced differences from the muscles of the control groups of chickens. The structure of myofibrils is clearly expressed, an even arrangement of muscle fibers is noted, with narrow gaps between them, longitudinal and transverse striation is well expressed, the color of the fibers is uniform.

7. Treatment of broiler chicken meat with ionizing radiation in doses of 2, 6 and 8 kGy leads to a slight decrease in the biological value of meat in terms of digestibility and harmlessness, in experiments on laboratory animals, the OBC decreases by 0.5%, which confirms the safety of irradiated meat for consumers.

8. To increase the shelf life of chilled and frozen meat of broiler chickens, it is advisable to sterilize with ionizing radiation in doses of 2 and 6 kGy.

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TECHNOLOGY OF LOW-CALORIE MAYONNAISE SAUCE OF INCREASED NUTRITIONAL AND BIOLOGICAL VALUE

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Abstract. *The scientific work is devoted to a topical topic, namely the development of low-calorie mayonnaise sauce technology. Monitoring of the market of mayonnaise sauces in Ukraine showed that this product is in high demand among the population, but the assortment of mayonnaise sauces with increased nutritional and biological value is not sufficient and needs to be expanded. On the other hand, an urgent task for scientists is the creation of resource-saving technologies for the processing of cheap secondary raw materials: the decoction obtained after cooking legumes - aquafaba. These secondary products are currently not used by industry.*

The paper presents research on the technology of low-calorie mayonnaise sauce based on aquafaba and resistant porous starch enriched with quercetin, as well as the results of its quality assessment. This product will be of interest to vegetarians who do not eat food prepared from animal raw materials.

The technology of resistant porous starch is substantiated and highlighted in our previous works.

Key words: *mayonnaise sauce, low-calorie, aquafaba, porous starch, quercetin.*

I. INTRODUCTION

The requirements of nutrition science indicate the need for a new approach to the formation of the composition and properties of food products. Consumers are increasingly interested in the impact of various food products and their components on health, so it is urgent to create new food products that positively affect the functions of the human body. In the world, the study of ways of enriching food products with biologically active substances of natural origin arouses the interest of scientists.

The search for natural sorbents, which, without changing the taste and being neutral regarding the physiological effect on the body, are able to retain certain low-molecular biologically active compounds and exert a protective effect on them is relevant. These substances change the role of micro, which ensures the stability of vitamins and mineral supplements, for example, which are sensitive to ultraviolet radiation, light, oxygen, metals, humidity, and temperature changes. As a material for microcapsules, it is known to use proteins, and polysaccharides, in particular starch [9-12, 19]. By purposefully changing the structure of the material, it is possible to obtain starch, which can be a carrier and protective agent for biologically active substances, and show resistance to the action of enzymes in the gastrointestinal tract. Such modified starch can be used in the technology of food products to enrich them and provide structure and certain functional properties [2, 3].

Among the products of the restaurant industry, sauces are a separate segment. The variety of flavors of world cuisine is created with the help of sauces. Sauces

contribute to better assimilation of food nutrients by the human body, expand the assortment and increase the nutritional value of dishes [21].

Mayonnaise sauces are cold cooking sauces for which oil is used. Oil is an important source of unsaturated fatty acids, which play an important role in human nutrition. However, an excess of fat in a person's diet is harmful because it causes digestive disorders. In the production of low-fat mayonnaise, hydrocolloids - fat imitators are used to correcting the rich creamy taste. For the partial replacement of fats, modified starches are widely used, which exhibit the properties of emulsifiers, fillers, and thickeners. Usually, this effect is achieved with the necessary concentration of starch in water [3, 15]. The introduction of various natural plant ingredients into the traditional recipe of mayonnaise products makes it possible to recommend it for use by various groups of the population.

One of the trends in the creation of food products for health and preventive purposes is the exclusion of allergens and proteins of animal origin. The two main components of mayonnaise sauce are eggs and oil. It is known that eggs are the most common allergens that often cause a negative reaction in children. Avoiding the use of eggs is also important for people who follow a vegetarian diet [25, 27].

Mayonnaise products are highly popular among the population of Ukraine and occupy an important place in the nutrition structure. The industrial production of these food products is becoming more and more widespread, which requires manufacturers to expand the range of these products. Today, there is a shortage of low-calorie mayonnaises with useful natural health supplements on the market. To expand the range of structured products for special dietary purposes - sauces, creams - it is promising to use vegetable raw materials, which are grown in large quantities in Ukraine. Such relatively cheap raw materials are legumes, such as chickpeas, peas, and beans, which contain a significant amount of protein substances and starch, as well as sugars, saponins, and other organic substances. The decoction of legume fruits is called «aquafaba» (from lat. aqua — water, faba — beans) and is used in culinary practice as an emulsifier and foam stabilizer instead of egg white [1, 5, 7].

Therefore, the development of low-calorie mayonnaise technology with increased nutritional and biological value is an urgent task.

The purpose of the work is the scientific justification and development of the technology of low-calorie mayonnaise sauce of increased nutritional and biological value based on modified resistant enriched starch and aquafaba.

II. LITERATURE ANALYSIS

Mayonnaise sauces occupy one of the leading places in the consumer market of Ukraine. The intensifying competition between manufacturers and trade organizations forces them to look for new means of influencing the decisions and motivation of consumers when choosing emulsion products. One of the ways to solve this problem is the expansion of the range of emulsion products, the introduction into production of low-calorie mayonnaise and sauces enriched with useful, natural additives for health and preventive purposes, which will help not only to satisfy the demand and tastes of consumers but also to ensure the healthy nutrition of the nation [7, 13, 14, 20].

Prospective directions for expanding the assortment and increasing the

nutritional value of sauces are the use of new types of raw materials, natural flavoring and flavoring and dietary additives; introduction of plant and animal fillers; reduction of the energy value of special purpose sauces (for dietary nutrition); development of semi-finished sauces of various degrees of readiness, in particular, vegetable concentrates with increased content of biologically active substances; improving the functional and technological properties of sauces, in particular, increasing their colloid stability due to the introduction of emulsifiers, thickeners, and stabilizers; increasing the economic efficiency of production.

The market of mayonnaise is considered quite flexible and mobile. Cold sauces (due to the short shelf life compared to other types of oil and fat products) are made to the order of the trade, which monitors the needs of consumers [21]. The mayonnaise segment occupies more than 60% of the sauce production structure by product category.

However, starting in 2012, the consumption of mayonnaise began to noticeably decrease. This product is associated among consumers with harmful food that hurts the body, and that is why a significant part of buyers tries to reduce its consumption.

Based on the volumes of consumption, the task of creating innovative types of mayonnaise products that will have new consumer properties, including enriched products, which will allow increasing the consumption of vegetable oils and reducing the deficit in particularly valuable nutrients [13-16] is urgent.

In Ukraine, the segment of low-calorie emulsion products is represented, for the most part, by mayonnaises and sauces with the addition of spicy and aromatic additives, spices, greens, etc. Some scientists are researching the use of diacylglycerols and blends of vegetable oils in mayonnaise technology, while the world is widely researching the development of innovative mayonnaise technologies enriched with prebiotics or biologically active substances of plant raw materials [15-17]. Emulsion fat products (in particular, mayonnaise and sauces) are enriched with biologically active substances, which are not available on the country's market. Therefore, the scientific and practical substantiation of the technologies of new innovative products - low-calorie functional purpose mayonnaises, enriched with biologically active compounds, is an urgent task.

2.1. Vegetable proteins as emulsifiers in the technology of emulsion food products

In addition to traditional components, mayonnaises include emulsifiers, stabilizers, structure formers, as well as taste, functional and other food additives that give mayonnaise different tastes, aromas, nutritional and physiological value and allow to create of a large assortment of these products [20].

In the production of mayonnaise, various combinations of emulsifiers are most often used, which makes it possible to obtain highly stable emulsions with lower consumption of emulsifiers. Egg powder, which is a protein-phospholipid complex, is used as the main emulsifying component. Egg yolk forms the basis of the emulsion and affects the stability, consistency, color, and taste of the finished product [7, 22]. The emulsifying effect of egg yolk or egg powder is caused by lecithin and other phospholipids. The following types of egg products are used: egg powder, granulated

egg product, and dry egg yolk. The content of egg products in mayonnaise, depending on the recipe, ranges from 2 to 6% [23, 24].

Emulsifiers traditionally used in the production of mayonnaise are also skim milk and whey protein concentrate, which has high emulsifying properties and is widely used as a full-fledged substitute for egg powder in the production of mayonnaise and low-calorie salad dressings [16, 17, 22].

Vegetable proteins, most often soy, are used as emulsifiers. Today, an alternative to egg white is «aquafaba» - an ideal option for those who cannot eat eggs or who are fasting. It is also valued among vegetarians, as it can imitate the properties of egg whites and dairy products, and is used as a vegetable emulsifier in many bakery products. It should be noted that dishes prepared using aquafaba almost do not differ in taste from those using eggs.

Aquafaba, the thick liquid left over from cooking legumes such as chickpeas or beans, is suitable for making meringue, pasta cakes, ice cream, mayonnaise, and more. Like egg white, aquafaba after whipping can form a stable foam that does not settle for a long time [27, 28].

Legume seeds or fruits are mainly composed of carbohydrates (starch, sucrose, and fiber), proteins (albumins and globulins), and water. A typical nutritional composition of chickpeas is 19% protein, 61% carbohydrates, 6% lipids, and 14% water. In the process of boiling legumes, the starch in the fruits is pasteurized. This contributes to the fact that soluble particles of starch pass into the liquid in which they are cooked. After the beans have been boiled, they are separated from the liquid phase. The resulting liquid, containing water-soluble substances of legumes, remains. It is called aquafaba. This liquid can be frozen and stored for a long time. Under normal conditions, approximately 5% of the bean composition turns into liquid. Thanks to this, aquafaba acquires its emulsifying and structure-forming properties. It is known that bean isolate has a high fat-holding capacity [22, 26].

From the analysis of literary sources, it is known that bean proteins are represented by globulins (salt-soluble proteins) - about 55%; albumins (water-soluble) - about 19%; glutelins (not soluble in water) - about 18%. The fraction of prolamins are absent [1, 7]. In addition, it is known [27] that the starch grains of legumes contain a significant amount of amylose - the linear fraction of starch polysaccharides - which to some extent determines the structure-forming properties of aquafaba.

White bean proteins are distinguished by a high content of such essential amino acids as leucine – 17.4 g/100g, lysine – 15.9 g/100g, phenylalanine + tyrosine – 11.3 g/100g, valine – 11.2 g/100g. According to the results of the analysis of the amino acid composition [22-24], it was established that the sum of essential amino acids in whey exceeds their amount in ideal protein by 1.9 times, and in white beans by 2.2 times.

In addition, white beans are rich in macro- and microelements: 100 g satisfies the daily need for potassium by 22-44%, magnesium by 20-34%, phosphorus by 45%, calcium by 13%, and among microelements, 100 g of beans most satisfy the daily need for iron - 30-59%; manganese - 67%; copper – 58%; molybdenum - up to 50% and zinc - 29-32%. Beans are also rich in B vitamins and tocopherol (E).

In the industrial production of legumes, aquafaba is a waste, so the development of sauce products using aquafaba as an emulsifier and structure former is promising [1,

7, 28]. Thus, the use of aquafaba will increase the nutritional and biological value of low-calorie mayonnaise sauces, exclude eggs from the recipe of sauce products and create an emulsion mayonnaise sauce for special dietary consumption.

2.2. Starch-based emulsion stabilizers

In some cases, only an emulsifier is enough to form a stable emulsion of high-calorie mayonnaise. If the fat content is reduced, stabilizers are added to the formulations, which ensure their stability and prevent delamination. They help to increase the viscosity of the dispersed medium, prevent the coalescence of small oil droplets, and therefore are hydrophilic in nature [2-4]. In the production of low-fat mayonnaise, modified starches are widely used to partially replace fats, which exhibit the properties of emulsifiers, fillers, and thickeners [16, 17].

Modified is a starch with directionally changed properties as a result of physical, chemical, biochemical, or combined processing. As a result, the natural features are significantly changed, sometimes the undesirable properties of polysaccharides are eliminated or reduced, and their valuable properties are strengthened. These products are classified as food additives.

For example, modified starches from Emsland-Starke GmbH (Germany) go through the stages of swelling and heating in the production process, so they can be dissolved in cold water. They are successfully used in the «cold» technology of preparing mayonnaise emulsions [21].

In addition to providing stable rheological characteristics of emulsion sauce, modified starch can serve as a protective material for biologically active substances. It is known that by freezing starch pellets under certain conditions it is possible to obtain porous starch with pores of different sizes. The formation of porous starch can occur as a result of ice formation in pastes. At the same time, strong frameworks are formed from starch with ice crystals included in them [3-4, 11, 13]. Porous starches have a highly developed surface. In a partially dehydrated state, they absorb a large amount of water. This type of starch is similar to a microcapsule that contains and stores active substances.

Scientific literature mentions the use of porous starch for food purposes after impregnation with sugar syrups, fruit and berry syrups, broths, and other liquid fillers. In the USA, porous starch has found use in medicine. Assumptions were made before the use of porous starches as adsorbents for special purposes, for the preparation of «dry perfumes». They can be useful as capsules for aroma oils, antioxidants, medicines, and agricultural materials for grain coating [11, 12].

Today, the relevance of using preparations from plant raw materials is increasing. Their advantage is low toxicity and the possibility of long-term use without the risk of side effects [19, 10].

Of particular interest are flavonoids, which are found in almost all plants to a greater or lesser extent.

Increased interest in flavonoids is due to their high and diverse biological activity. The low toxicity of flavonoid compounds, along with the selective pharmacological effect on the human body, makes it possible to widely involve them in the creation of new medicinal preparations [12, 13].

As medicinal products, the flavonols rutin and quercetin, which belong to the group of vitamin P, are of practical use. They are especially rich in green tea leaves, buckwheat flowers and leaves, Japanese sophora, citrus fruits, rose hips, and mountain ash.

Quercetin dilates blood vessels, increases their tone, and exhibits antispasmodic properties. It is used for increased permeability and fragility of capillaries in hypertension, atherosclerosis, and rheumatism. Having antioxidant properties, quercetin protects cell membranes and inhibits their aging process. In addition, this flavonoid prevents the accumulation of cholesterol on the walls of blood vessels. Regular consumption of quercetin normalizes blood pressure, improves blood circulation, and significantly reduces the risk of cardiovascular diseases and the formation of blood clots. Therefore, in our opinion, the use of quercitin to enrich the mayonnaise sauce would be appropriate. As a neutral carrier for quercitin and to protect it from the environment, it was decided to use porous modified starch.

Modified starch, in addition, should play the role of not only a hydrophilic carrier for quercitin but also filler, an emulsion stabilizer, while not affecting the glycemic index of the product. This is because, during the freezing and thawing of starch pastes, a partial retrogradation of starch polysaccharides takes place with the formation of a strong structure that is not susceptible to the action of enzymes of the gastrointestinal tract. That is, the obtained modified starch belongs to the group of resistant. Resistant starch is of interest to food developers and nutritionists for two reasons, the first being the physiological benefits and the second being the unique functional properties that cannot be obtained with traditional insoluble dietary fibers. Resistant starch improves the color and taste of some foods compared to the use of traditional insoluble dietary fibers [2-4].

Therefore, based on the analysis of literary sources, research tasks were formulated: to investigate the possibility of obtaining a vitamin complex of quercetin by its sorption on porous starch; to investigate the emulsifying properties of the system: porous starch with quercitin - aquafaba - sunflower oil; to develop the technology of low-calorie mayonnaise sauce of increased nutritional and biological value; provide a qualitative assessment of the developed sauce.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The *object of research* is the technology of low-calorie mayonnaise sauce with increased nutritional and biological value.

The *subject of research* is modified corn starch with quercetin; aquafaba - liquid obtained as a result of boiling white beans; vegetable oil, model compositions of emulsion sauces with different ratios of aquafaba and emulsified oil; emulsion sauce.

Preparation of aquafaba. To prepare aquafaba, white beans or chickpeas were soaked for 2 hours and boiled for 60 minutes with a ratio of beans to the water of 1.5: 3.5. The strained liquid (aquafaba) was cooled.

All raw materials and materials used in the research, in terms of quality and safety, met the requirements of the regulatory documentation in force in Ukraine or the quality certificates of the manufacturers and were approved for use by the Ministry of Health of Ukraine.

Preparation of porous starch with quercetin. The technique [4, 11, 12] modified by us was used to prepare porous starch with quercetin. A suspension of 40 (20) g of air-dry corn starch was prepared with a concentration of 10% using a quercetin solution with a concentration of 1% as the aqueous phase. For the pasteurization of starch, the suspension of starch with quercetin was treated in a microwave oven for 5 min at medium power. When the paste cooled, it was necessary to avoid the formation of a film on the surface. Next, the starch paste was subjected to freezing at temperatures of –5…–10 °C for 12…15 hours. For rapid thawing, the frozen mass was heated to 30…35 °C. Then water was squeezed out of the spongy structure of retrograded starch, and dehydrated with ethanol. The resulting structure was quite strong and flexible, able to recover after removing the load. The obtained sample was dried at a temperature of 45 °C, crushed, and sieved.

Research methods – standard generally accepted and special physicochemical, organoleptic, mathematical, and statistical methods of processing experimental data using modern computer programs.

X-ray diffraction analysis (XRD) of the initial forms of corn starch, quercetin, and the resulting product was carried out on a DRON-M1 X-ray diffractometer with two Soler slits.

The resulting starch was examined using an scanning electronic microscope LEO 1420 (Germany).

Determination of the content of amino acids in mayonnaise sauce was carried out in the laboratories of the Institute of Food Resources of the National Academy of Sciences of Ukraine (Kyiv).

Resistance property of criomodified starch was investigated by a procedure using 3,5-dinitrosalicylic acid [2].

Emulsion stability – a conventional unit that indicates the percent of intact emulsion remaining after stability studies – was determined according to the approved methodology (DSTU 30004.2).

Mayonnaise sauce was obtained by emulsification using a laboratory top-drive mixer ULAB US-2000A.

IV. RESULTS

4.1. Study of the structure and properties of porous starch with quercetin (PSK)

In order to obtain porous starch, information was used that during deep freezing of starch pastes, the formation of ice crystals leads to the compaction of polysaccharide chains (retrogradation) and the formation of internal channels.

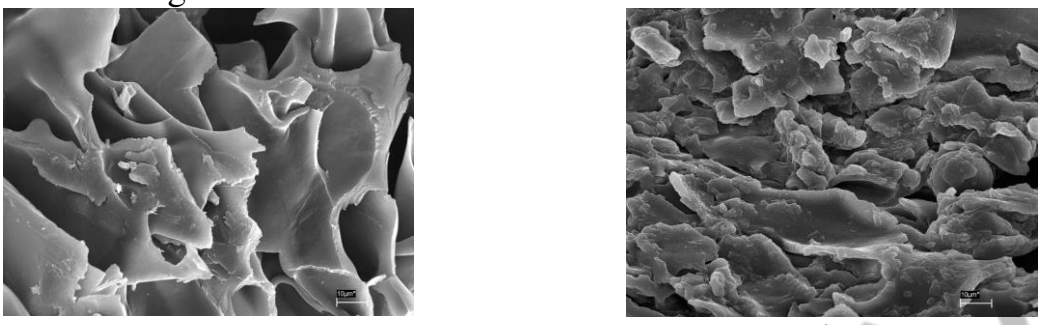
As a result of thawing the frozen starches paste, water syneresis occurs from the starch gel. The combination of freezing-thawing stages leads to the formation of resistant starch.

The formation of pores of different sizes depends on the concentration of starch paste. We used 10% starch paste to make porous starch.

It was assumed that, due to the porous structure, such a modified starch can adsorb low molecular weight biologically active substances. In our study, we used the

flavonol quercetin.

A sample of porous starch with quercetin was obtained by the method described above. It was investigated in order to refine the structure.

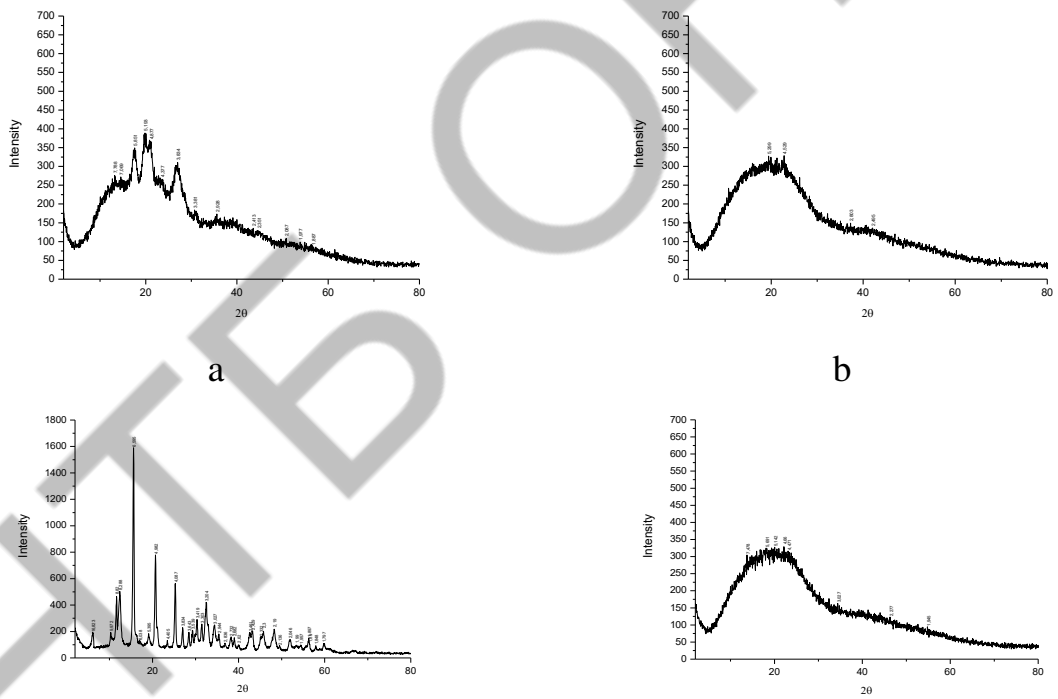


a b

Fig. 1. Micrograph of sections of porous starch taken with a skinning electron microscope: a – cross section, b – longitudinal section

Microphotographs of sections of porous corn starch (Fig. 1), taken with a scanning electron microscope, clearly show the structure of pores.

The results of X-ray phase analysis of corn native and porous starches, as well as quercetin and porous starch with quercetin are presented in fig. 2.



a b

c d

Fig. 2. Radiographs of samples: a – corn starch, b – porous corn starch, c – quercitin, d – porous corn starch with quercetin

Analysis of radiographs showed changes in crystallinity that occurs during freezing-thawing of starch pastes. Native starch has an amorphous-crystalline structure, as evidenced by the X-ray pattern shown in Fig. 2, a. Porous starch has an amorphous structure with barely noticeable remains of crystallinity (Fig. 2, b). The quercetin used in the work gave its characteristic diffraction pattern (Fig. 2, c).

X-ray phase analysis of the product of the interaction of porous corn starch with quercetin showed (Fig. 2, d) that quercetin in it is in a non-crystalline form (or in the form of crystals with a size of less than 10^{-9} m) while preserving the amorphous form of porous starch.

The degree of resistance was determined by the residual content of reducing substances after enzymatic hydrolysis of starch with the enzyme preparation «Pancreatin», which contains digestive enzymes [2, 3].

Research results show that porous starch has greater resistance to enzymatic hydrolysis than native starch. As the concentration of the starches paste from which the porous starch was prepared decreases, its resistance to the action of enzymes decreases. The degree of resistance of the obtained starch is about 60 %. Thus, the use of porous resistant starch with quercetin in food products will allow enriching the products with quercetin, while most of the starch will be removed from the organism.

Based on the analysis of literary sources and our own research on the technology of resistant PSK, the following tasks were formulated: to combine in the development of an emulsion product PSK and aquafaba as a basis; experimentally determine the amount of oil and the conditions of emulsion stability over time.

4.2. Investigation of the emulsion stability based on aquafaba and PSK

The innovative production model of the new generation mayonnaise sauce involves the use of a mixture of aquafaba sunflower oil, which has emulsifying and structure-forming properties, and porous resistant starch enriched with quercetin as the main component.

A study was conducted to determine the influence of the amount of aquafaba and oil on the stability of the emulsion. It was established that with an increase in the oil content, the stability of the emulsion increases (Fig. 3). Thus, with an aquafaba content of 40...60% and an oil content of 60%, the stability of the emulsion is 98±2%, which meets the requirements of regulatory documentation for mayonnaise.

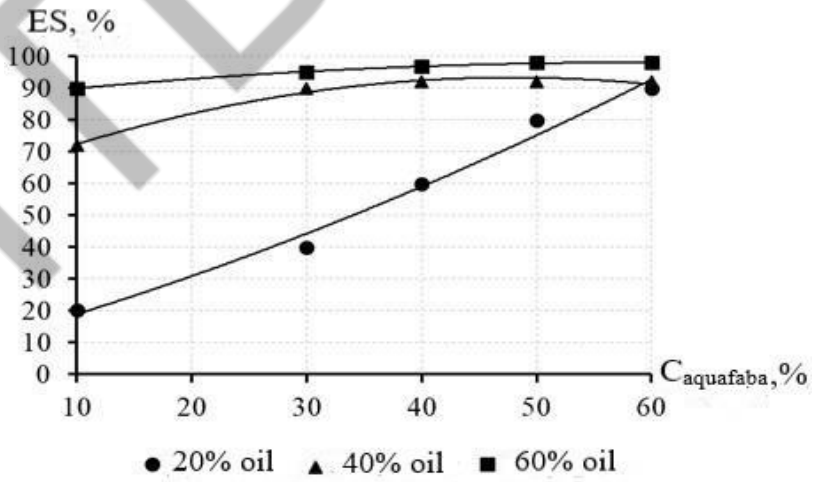


Fig. 3. Emulsion stability depending on aquafaba and sunflower oil content, %

It should be noted that systems with an oil content of 40% (which meets the requirements for a low-calorie mayonnaise sauce) and with an aquafaba content of 40...60%, the stability of the emulsion is 94±2% and practically does not change, although the viscosity of the system in this range increases. The addition of porous

starch with quercetin makes it possible to increase the stability of the emulsion to the normative value, not lower than 97%. Based on the analysis of emulsion stability values, it is possible to recommend a rational ratio for obtaining low-calorie emulsion sauces - Aquafaba: oil = 40...60 : 40.

The principle technological scheme (Fig. 4) provides for the preparation of aquafaba by cooling and emulsification, the gradual addition of porous starch with quercetin and mustard, mixing until a homogeneous mass is formed. To form a stable emulsion, the oil is injected in a thin stream during vigorous emulsification of the product.

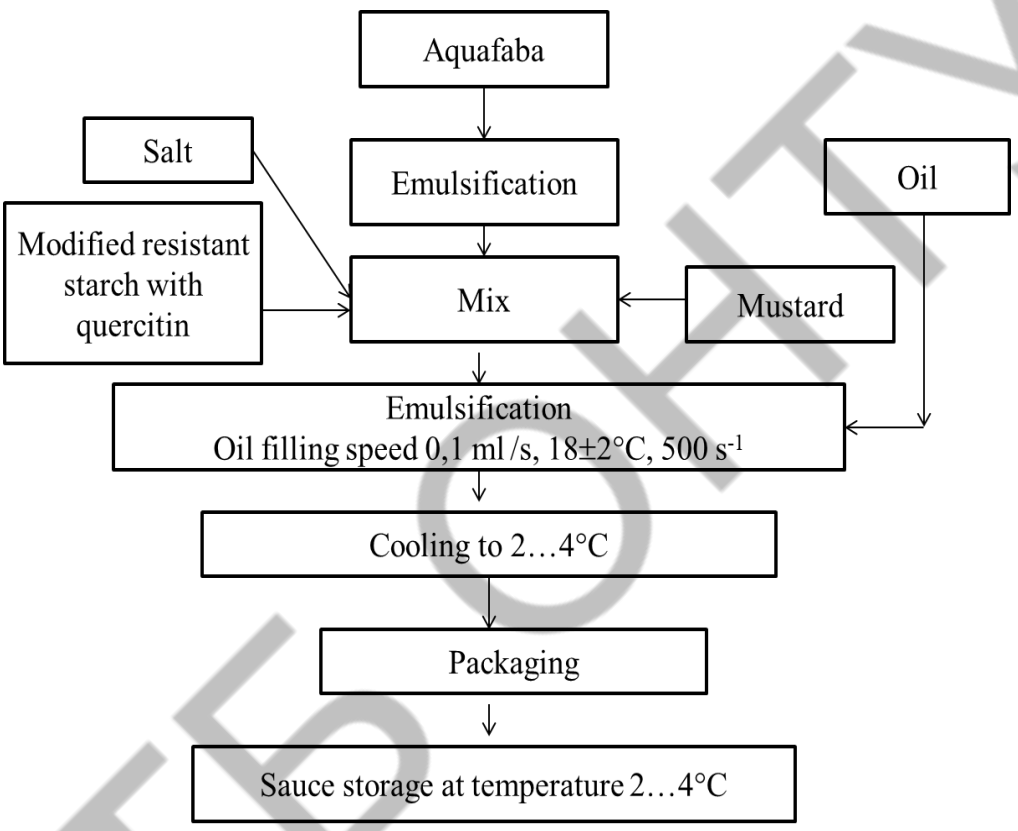


Fig. 4. Principle technological scheme for the production of low-calorie mayonnaise sauce

The technological scheme for the production of mayonnaise sauce provides for the addition of oil to the mixture of dispersed aquafaba and PSK (4…5%). The emulsification process was carried out at an oil addition rate of 0.1 ml/s at a temperature of 17...20 °C while rotating the stirrer at a speed of 500 s^{-1} for (1.1...1.2)× 60 s (laboratory stirrer ULAB US-2000A) to prevent stratification of the system (Fig. 4).

On the basis of the conducted research, the recipe of low-calorie mayonnaise sauce «AQUAFABA» was developed based on a decoction of white beans with the addition of resistant porous starch with quercetin (table. 1).

Table 1. Recipe composition of emulsion sauce «AQUAFABA»

Component name	Recipe composition of the sauce	
	Brutto, g	Netto, g
Refined, deodorized sunflower oil	40	40
Porous starch with quercetin	5	5
Aquafaba	50	50
Mustard	5	5
Salt	0,5	0,5
Output of the finished product	-	100

The developed mayonnaise sauce can be recommended for any dishes, in particular, for salads and white meat.

4.3. Research on the quality of low-calorie mayonnaise sauce «AQUAFABA»

The obtained low-calorie mayonnaise sauce is characterized by a complex of quality indicators, among which the most important are nutritional and biological value.

The content of the main food substances and the energy value of the emulsion-type sauce compared to the control are shown in the Table 2. The classical recipe of «Provencal» mayonnaise with a fat content of 67% was used as a control.

Table 2. Chemical composition and energy value of the sauce, g/100g of product

Indicator	Unit of measurement	Sauce	
		Control	«AQUAFABA»
The mass fraction: - moisture	g/100g of product	21	25
- mineral elements		1,5	3,36
- proteins		2,8	5,7
- fats		67	40
- carbohydrates		3,7	22
Energy value	Kcal	629	345

The developed mayonnaise sauce is characterized by an increased content of proteins and minerals compared to the control. The amount of carbohydrates increased by almost 6 times due to the use of white bean decoction (aquafaba). Fat content and energy value, on the contrary, decreased due to a decrease in oil content.

The analysis of the amino acid composition of the proteins of the sauce (Table 3) showed that due to the proteins of the beans, the mayonnaise sauce «AQUAFABA» is characterized by a significant increase in all amino acids compared to the control, including essential. In particular, the content of valine, isoleucine, leucine and lysine increased approximately 2 times. The content of threonine and tryptophan increased by 2.6 and 2.8 times, respectively. The content of methionine and phenylalanine increased by more than 1.5 times compared to the control sample. A decrease in the content of arginine and glutamic acid was noted. The ratio between amino acids has

changed, which is explained by the presence of proteins of plant origin only in the composition of the sauce.

Table 3. Amino acid composition of proteins of «AQUAFABA» mayonnaise sauce compared to the control

Amino acid	Control	Sauce «AQUAFABA»	Deviation, %
Essential:			
Valin	93	187	101,08
Isoleucine	90	192	113,33
Leucine	137	316	130,66
Lysine	115	273	137,39
Methionine	42	64	52,38
Threonine	82	217	164,63
Tryptophan	20	55	175,00
Phenylalanine	69	110	59,42
Substitute:			
Alanine	84	161	91,67
Arginine	115	104	–9,57
Aspartic acid	113	343	203,54
Histidine	38	64	68,42
Glycine	50	77	54,00
Glutamic acid	203	66	–67,49
Proline	69	209	202,90
Serin	136	167	22,79
Tyrosine	69	98	42,03
Cystine	28	67	139,29

Mayonnaise sauce is characterized by an increased content of vitamins C, A and group B, P (bioflavonoids); of minerals – K, Ca, Mg, P. The use of aquafaba, which is a solution of high-molecular compounds of legumes, contributed to the appearance of vitamins B_5, B_9, B_{12} and E in the sauce.

According to our calculations, 100 g of mayonnaise sauce contains about 400 mg of flavonol quercetin due to its introduction into the recipe with porous starch. Given the recommendation to consume 500 to 1,000 mg of quercetin per day for preventive purposes, eating a low-calorie mayonnaise sauce will help ensure the daily need for this vitamin.

Resistant starch is classified as a new type of dietary fiber. Its presence gives products new functional properties: increasing the feeling of satiety, suppressing hunger, which prevents excessive food consumption and reduces the risk of obesity

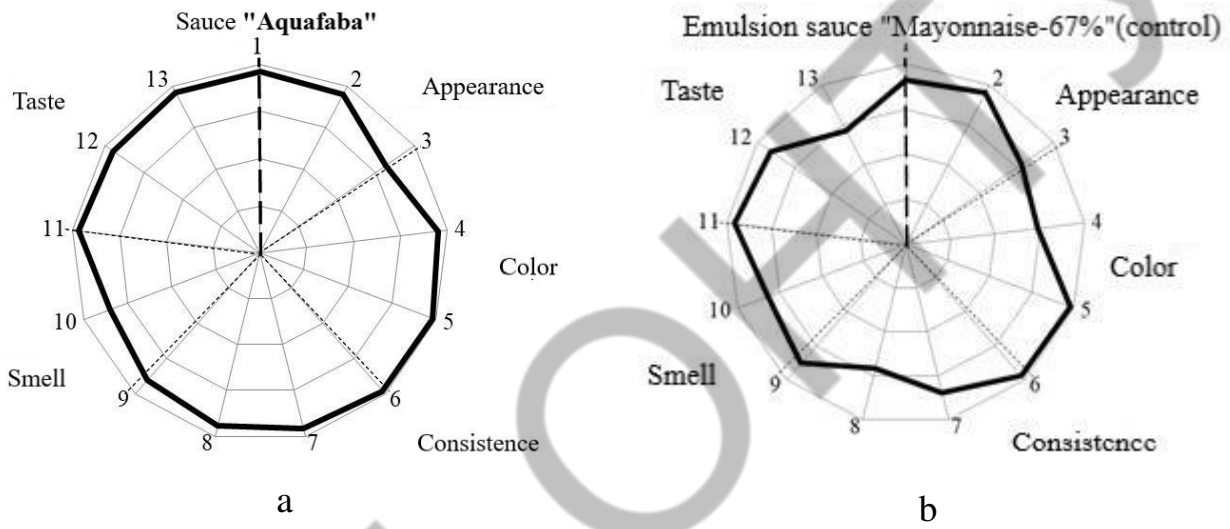
The obtained data confirm that the use of aquafaba and porous starch with quercetin in the base of emulsion sauces contributes to the enrichment of the final product with vegetable proteins, essential amino acids, carbohydrates, vitamins and mineral elements.

Emulsion sauce based on MRK and aquafaba has an attractive appearance, improved color compared to control samples, balanced taste and aroma indicators, uniform consistency (Table 4).

Table 4. Organoleptic characteristics of «Aquafaba» emulsion sauce

Organoleptic indicators			
Appearance	**Color**	**Taste and smell**	**Consistence**
A thick, structured low-flowing mass, without flouriness and sediment, without delamination	The light cream color is uniform over the entire mass, the surface is glossy	Clean, without extraneous odors, without pronounced smell, sour-salty taste, without extraneous flavors	Uniform consistency, without delamination, without crystallization centers

The organoleptic profile of the emulsion sauce "AQUAFABA" and the control sauce «Mayonnaise - 67%» is presented in Fig. 5.



a b

Fig. 5. Organoleptic profile: a – «AQUAFABA» sauce (S=5.24), b – control (S=4.87)

From the analysis of profilograms (Fig. 5), it can be seen that the set of defining characteristics of organoleptic indicators is more balanced in the low-calorie mayonnaise sauce according to the developed technology compared to the control.

V. CONCLUSIONS

Based on the results of the research, a resource-saving technology of low-calorie mayonnaise sauce of increased nutritional and biological value was developed with the replacement of egg whites with aquafaba - a decoction of white beans and with the addition of resistant porous starch with quercetin. The perspective of using aquafaba and modified starch to regulate the emulsifying and stabilizing properties of the sauce has been proven. The rational ratio of aquafaba and vegetable oil as (40...60) : 40 is substantiated, which makes it possible to obtain emulsion systems with a stability of 97±2%.

The formulation of emulsion low-lactose sauce «AQUAFABA» was developed, its chemical composition and energy value were determined.

The developed mayonnaise sauce is characterized by an increased content of proteins and minerals compared to the control. The amount of carbohydrates increased

by almost 6 times due to the use of white bean decoction (aquafaba) and porous starch with quercetin. Fat content and energy value, on the contrary, decreased due to a decrease in oil content.

An organoleptic evaluation of the quality of the developed sauce was carried out and it was established that the set of defining characteristics of organoleptic indicators is more balanced in the «AQUAFABA» emulsion sauce compared to the control.

The social effect of the introduction of the developed technology of low-calorie mayonnaise sauce consists in providing the population with a product of daily use of increased nutritional and biological value. This product will be of interest to vegetarians who do not eat food prepared from animal raw materials.

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SCIENTIFIC AND PRACTICAL FUNDAMENTALS OF PRODUCTION COMPOUND FEEDS FOR DECORATIVE AND SINGING BIRDS

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Abstract. *According to FEDIAF, decorative and singing birds are the third largest pet population in the world. Analyzing the feed market for decorative and singing birds in Ukraine, we saw that a significant part of it is occupied by imported feeds, while the assortment of domestic feeds on the market is very small and does not always meet the requirements and cannot withstand competition. However, it is difficult to call the presented feeds complete, since they are mainly different types of feed mixtures and molded treats, which, depending on the price category, include different types of components: starting with cereals and ending with various nuts, dried fruits, etc. This creates significant economic potential with the introduction of modern technologies for the production of competitive fodder for decorative and singing birds, which will allow to significantly diversify and expand their range.*

The paper substantiates the expediency of the production of compound feed for decorative and singing birds, the peculiarities of the digestion process and the role of the main nutrients for decorative and singing birds are studied, and the classification of feed is developed. The object, subject and research methods are selected. Recipes of compound feed are calculated and theoretical justification of the method of production of compound feed for decorative and singing birds is given. Experimental samples were obtained in laboratory conditions and the main quality indicators were studied. A comparative analysis of the obtained compound feed with industrial feed was carried out. It was established that these feeds meet the needs of poultry in terms of the main nutritional indicators and are not inferior to industrial analogues.

Keywords: *pet food market, decorative and singing birds, assortment, classification, fodder, compound feed, recipe, extrusion, quality indicators.*

I. INTRODUCTION

In the developed countries of the world, animal business is one of the most profitable and promising branches of production. Pet business includes the totality and interaction between enterprises engaged in the production and distribution of goods and services for pets, and consumers of these goods and services. The term "zoobusiness" used in Ukraine corresponds to the concept of "Pet industry". The prospects of activities that include pet business are due to the constant growth of the number of domestic animals around the world. The term "pets" usually includes cats, dogs, decorative and singing birds, rodents, aquarium fish, reptiles and amphibians, which are united by the word "pets" abroad. The structure of pet business is represented by pet products (feeds (compound feeds), medicines, care products and accessories), services and animals [1].

Today, the owners of decorative and singing birds do not have a wide range of ready-made feed at their disposal, compared to feed for cats and dogs. Analyzing the

feed market for decorative and singing birds, we saw that a significant part of it is occupied by imported feeds, while the assortment of domestic feeds on the Ukrainian market is not large and does not always meet market requirements and cannot withstand competition. However, it is difficult to call the presented feeds complete, since they are mainly different types of feed mixtures, which include, depending on the price category, different types of components: starting with cereals and ending with various nuts, dried fruits, etc.

Ready-made feeds in combination with a correctly selected feeding regime strengthen the health of birds, and also meet their expectations regarding taste qualities and the owner's expectations regarding the price and convenience of feeding. Careful observation of the appearance and behavior of birds allows you to establish the correct diet for your pet and determine his preferences for one or another type of feed.

This creates significant economic potential with the introduction of modern technologies for the production of competitive fodder for decorative and singing birds, which will allow to significantly diversify and expand their range.

The purpose of this work is to develop recipes, increase the feed value and expand the range of feed for decorative and songbirds by extruding the formed initial mixture with the inclusion of fruit and vegetable extracts with the subsequent production of grits. To achieve the set goal, it was necessary to solve the following tasks:

– conduct an analysis of the pet food market in Ukraine;

– to study the peculiarities of the digestive process of decorative and singing birds and the role of the main nutrients in the composition of feed;

– to develop a classification of fodder for decorative and singing birds and to analyze the methods and technologies of their production;

– calculate recipes of compound feed for decorative and singing birds;

– to improve the technological method of production of compound feed for decorative and singing birds;

– to evaluate the quality of experimental samples and industrially produced feeds according to organoleptic, physico-chemical and microbiological indicators.

II. LITERATURE ANALYSIS
Prospects for the production of compound fodder for decorative and singing birds in Ukraine

2.1. Analysis of the pet food market

The global pet food market was valued at USD 94.76 billion in 2021 and is expected to grow at a CAGR of 4.4% from 2022 to 2030. Increasing consumer awareness of natural and organic pet foods has forced manufacturers to shift their focus from synthetic to natural products, which has become one of the major forces influencing the global market today.

The COVID-19 pandemic has had a negative impact on supply chains. The pet food sector has been affected in terms of supply and cash flow due to restrictions on the movement of raw materials. On the other hand, demand for pet food has grown steadily in many parts of the world as people get more pets in response to the growing

desire for company during the quarantine. To meet this demand, market players have shifted their focus from brick-and-mortar stores to e-commerce platforms [2, 3].

In Ukraine, in 2017–2021, the category "Animals – pets and feed for them" in the structure of retail turnover occupied a share of 0.3-0.5 %. The volume of retail turnover during this period increased 3.4 times, from 1,612.5 million UAH in 2017 to 5,468.6 million UAH in 2021 [4].

According to FEDIAF, decorative and singing birds are the third largest pet population (cats and dogs, respectively, numbers 1 and 2), with 51.87 million decorative and singing birds across Europe (37.23 million of them in the European Union) in in 2020.

Business activity related to the production of pet food in Ukraine has existed for about 20 years, while in the developed countries of Europe and the USA, similar products have been sold for more than 150 years. At the same time, according to analysts of the Euromonitor International company, the Ukrainian pet food market is characterized as a fast-growing one. It is believed that Ukraine is on the 8th place in the TOP-10 fastest growing pet food markets. However, the Ukrainian feed market is dominated by foreign producers, in particular from such countries as Hungary, the USA, France and others.

Today, the Ukrainian cat and dog food market is worth about 300 million dollars a year. For comparison, the European market for pet food is more than 22 billion dollars per year, in the USA more than 11 billion dollars of feed is sold per year, and in Poland they spend 1 billion dollars annually [5].

About 10-15 % of the profit from the total sale of pet food comes from decorative and songbirds, rodents, aquarium fish and other exotic animals. Currently, a large number of ready-made feeds, mainly in the form of feed mixtures and treats for various types of poultry, have appeared on sale. Currently, there are about 20 brands of fodder for decorative and singing birds. Most of the feed suppliers on the market are foreign countries, such as Hungary, Germany, Belgium, Italy, Poland, etc. Among the domestic manufacturers, TM "Pryroda", TM "Lori", Hobby meal and others are represented on the market. Feeds of domestic producers are generally not expensive and according to the price criterion belong to the "economy" and "business" classes [6].

Based on the analysis of the world and Ukrainian markets for pets, the following main factors that influence their development can be identified: demographic changes (population size, population urbanization, "population aging", increasing the level of education); psychological changes (change in the role of animals, change in approaches to feeding animals); change in management (intensification of competition due to the consolidation of individual companies in the industry, continuation of the offensive of global corporations, increased competition between specialized and non-specialized stores, increasing importance of an established delivery system, reducing the number of links in the producer-consumer chain, increasing the role of innovative developments, new methods of marketing, packaging technologies in the development of competitive advantages).

2.2. The role of the main nutrients in the composition of feed and features of rations for decorative and singing birds

Decorative and singing birds, like all living things, need full nutrition to maintain vital activity and body health. The feed must contain all the components that are necessary for energy production, growth, tissue regeneration, as well as for the regulation of metabolism. A well-balanced feed should contain all the nutrients in a certain amount, and depending on the need for these substances in the bird, their ratio may be different. Factors such as species, age of birds, general health, level of physical activity, physiological state, housing conditions and even season must also be taken into account. In this regard, it is necessary to carefully research each class of nutrients and especially the formation of compound feed recipes taking into account the need for them for decorative and singing birds.

Of all animals on earth, birds have the highest body temperature of 41-42 degrees. Therefore, the metabolism that determines their life activity is very fast. The daily metabolic energy requirement for budgies is 70 – 85 kcal, for nymphs and roselles – 115 – 160 kcal, for gray parrots and cockatoos – 140 – 175 kcal. Proteins play an important role in the vital activity of the bird's body. Coming with food, they go to the restoration of old cells, the formation of muscle tissue and the growth of feathers. A lack of protein or an imbalance in its amino acid composition in the diet can cause a delay in the development of chicks, the bird becomes thin, blood quality deteriorates, and reproductive function decreases. For example, budgerigars should receive 3.2-4.0 g of crude protein per head per day, nymphs, rosellas – 5.2-7.0, gray parrots, cockatoos – 7.0-8.5, respectively. Fats are an essential component of protoplasm and play an important role in cellular metabolism. They are the most concentrated source of energy for the bird's body. Fats are an important source of reserve energy and can accumulate in the body in significant quantities (excessive accumulation of fats leads to obesity and reduced activity of birds). Carbohydrates are necessary for the body to ensure the work of muscles and organs, to maintain body temperature. An excess of carbohydrates is deposited in the liver in the form of glycogen and goes to the formation of fat, which is broken down when there is a lack of carbohydrates. With its lack in the diet, the internal reserves of the liver are used up, and after them, the fats and proteins of the body are destroyed. Carbohydrates are accumulated in the bird's body to produce energy, maintain body temperature, and form adipose tissue.

Vitamins are necessary for the normal functioning of the bird's body. With their lack or excess, the body's metabolism is disturbed, its resistance to diseases, reproductive capacity, etc., decreases. The need for vitamins especially increases during the molting and nesting period, as well as in the winter and spring period. After all, the egg laid by the female contains the entire complex of vitamins necessary for the further growth and development of the chick. If there is an insufficient amount of vitamins and other nutrients in the egg, then the chick either dies at a certain stage of development, or grows up weakened, prone to various diseases. The body of the female, having used the appropriate supply of vitamins for the formation of an egg, also needs to replenish this supply for the next egg-laying and normal functioning in the future. Some vitamins can accumulate in tissues and organs (for example, vitamin A – in the liver) and be used by the body from these reserves, and some, especially those vitamins that cannot be synthesized in the bird's body, must be supplied regularly with feed. Unlike proteins, fats, and carbohydrates, minerals have no nutritional value,

but they are extremely necessary for the bird's body as a plastic material (bone tissue) and as a regulator of metabolic processes involved in maintaining the appropriate level of osmotic pressure, acid-alkaline balance, as a structural element of enzyme systems, etc. Some of them are necessary in relatively large quantities, because they participate in the construction of various tissues of the body, for example, calcium, which is found in bones. Others, involved in chemical processes of metabolism, are needed in minimal quantities. The daily requirement of calcium for budgies is 120-160 mg, phosphorus – 120-140 mg, sodium – 50-60 mg.

Thus, a competently developed recipe for decorative and singing birds, taking into account the species, age of birds, physiological characteristics, conditions of keeping will be a guarantee of their health and longevity [7-9].

2.3. Classification and characteristics of fodder for decorative and singing birds

Taking into account the market analysis, as well as based on the study and generalization of literary and Internet sources, we propose to classify feed for decorative and singing birds by bird species, purpose, form of release, price, physiological features and age, as well as by type of packaging [10].

All domestic birds that are kept as pets can be divided into three varieties: singing (having a melodious voice), decorative (with original coloring), and parrots, which are a kind of hybrid of the first two species.

According to their purpose, complete ration feeds and grain feed mixes, treats and feeds fed for medi.al purposes are distinguished. Complete feed contains all nutrients and biologically active substances and is intended for everyday use. Manufacturers of grain feed mixtures also position them as complete ration feed. However, this is a mixture where it is possible to selectively eat feed components, which does not give it the right to be called complete nutrition. Medicinal feed is used for various poultry diseases. This feed has appropriate labeling and is prescribed on the recommendation of a veterinarian and is sold only in veterinary pharmacies. Treats (crackers, sticks for additional feeding, etc.) should be given infrequently and only from proven manufacturers of well-known brands. The glue with which the grain and nuts are attached to the base can contain a large amount of animal protein and, as a result, provoke a surge of sexual activity, and the grain in crackers and sticks is often expired or of low quality.

According to the form of release, loose fodder mixtures and molded fodder are presented on the market. The composition of fodder mixtures includes various types of components, starting with cereals, and ending with various nuts, dried fruits, etc. Formed, represented by a small amount of granulated feed and with a partial inclusion in the composition of the mixture of extruded additives in the form of balls, etc. The use of molded feeds causes a number of disputes among the owners of decorative and singing birds. Some bird owners refuse them, while others, on the contrary, cannot imagine the existence of their pets without them. In this case, it is necessary to take into account that the transition of birds, which have been used to eating mixtures of nuts and grains all their lives, to pellets and extrudates, may turn out to be an overwhelming task. Therefore, this process should be gradual and long-term, with

partial addition of new feed to the main habitual diet. Today, mainly granulated fodder is used in feeding macaws, gray parrots and cockatoos. It should be noted that in order to meet the feed needs of decorative and singing birds when they are kept in captivity, one of the most effective methods is the creation of complete ration compound feed through the use of innovative technologies. For example, in the form of grits or a mixture of grits obtained by extrusion. This will make it possible to diversify the diet, to ensure the satisfaction of both behavioral and feed needs of birds.

By price, fodder for decorative and singing birds is divided into three price categories: economy, business and premium classes. This formation of classes was developed based on the income of the population. Economy class includes consumers who can afford to buy food for their pets at a price of UAH 70 to 100 per kilogram, business class – UAH 101-250/kg, premium class - consumers who can buy food for of their pets is higher than UAH 251/kg. On the market, these classes can include the following feeds: economy class – "Bird", "Fruit-Menu", "LORIvit", etc.; business class – "Papuzhka", "Vitapol KARMEO", "RIO", "Padovan", Versele-Laga, etc.; premium class: "Fiori", "LoLo Pets", "Prestige", "VitaKraft", etc. Among the domestic manufacturers, TM "Pryroda", TM "Lori", Hobby meal are widely represented on the market. Feeds of domestic manufacturers are generally not expensive and according to the price characteristics, they belong to the economy and business class feeds.

Economy-class fodder is mainly domestically produced fodder. In their composition, they mainly contain various types of seeds of grain and oil crops, seeds of meadow grasses, etc. The assortment of business-class feeds includes both domestic and foreign manufacturers. It also contains various types of grain and oil seeds, as well as dried fruits, vegetables, peanuts, etc. Premium-class fodder – fodder enriched with various natural flavor additives, mainly imported. The composition may additionally contain flakes, extruded balls, mineral substances, oils and fats, honey, yeast, algae, etc. The difference between these feeds depends on their composition and nutrition.

By physiological characteristics and age, feed can be divided into feed for adult birds at rest, in the period before nesting, for females in the feeding period, for chicks and in the molting period. These feeds should contain the necessary amount of nutrients and biologically active substances in accordance with the norms and needs of poultry feeding in different periods of its life.

For example, in the period before nesting, i.e., the period when the female "fixes" her nest and when she lays eggs, the feed should be enriched, first of all, with calcium, vitamins and other mineral substances. During the nesting (egg hatching) period, the female almost does not get up from the nest, only when necessary, and she eats everything that the male brings her, therefore, this feed should meet the minimum requirements for nutrients and biologically active substances. During the period of feeding chicks and for chicks, feed should be enriched with proteins, fats, vitamins, amino acids and minerals, these feeds should be in an easily digestible form. During the molting period, feed should contain an increased content of protein and amino acids.

Depending on the type of packaging, feed for decorative and singing birds is currently offered in natural (cardboard), soft polymer and combined (based on cardboard and polyethylene) packages.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The object of the research is the technological process of extruding loose starting mixtures. The subject of the research is extruded compound feed in the form of grits for decorative and singing birds and feed for industrial production.

The described physico-chemical and microbiological research methods in accordance with the direction of the experiments are given in the table 3.1. For ease of use, all methods are systematized in accordance with research directions.

Table 3.1. Research methods used in experiments [11-13]

№	Name of indicatots	Principle of the method and its specifics	Regulatory and technical documentation (RTD)
Physical and chemical indicators			
1.	Mass fraction of moisture	Drying a test product weight to a constant mass at a temperature (130±2) ˚C	The State Standard DSTU ISO 6496:2005
2.	Volumetric mass	With the use of a liter powder (mass of raw maerials in one liter)	The State Standard GOST 28254-89
3.	Natural slope angle	On Zenkov's equipment by pouring from a watering can	The State Standard GOST 28254-89
4.	Fluidity	The flow rate if the product through an opening of a certain diameter	[13]
5.	Weighted average particle size	Sievsng a sample of bulk product on a set of sieves with holes of different diameters	The State Standard GOST 13496.8-96
6.	Crude protein	According to Kendall's method	The State Standard DSTU ISO 5983:2003
7.	Raw fat	By the Soxhlet method	The State Standard GOST 13496.15-97
8.	Crude fiber	Treatment of a sample of the experimental product with a mixture of concentrated nitric and acetic acids	The State Standard GOST 13496.4-93
9.	Raw ash	Incineration of a sample of the experimental product with subsequent calcinations of the mineral residue at a 500-600°C	The State Standard GOST 13496.14-87
10.	Calcium	Complex metric method	The State Standard GOST 26928-86
11.	Phosphorus	By the molybdenum-vanadium method	The State Standard GOST 26928-86

To assess the quantitative and qualitative composition of the microbiota, samples were taken in sterile dishes in aseptic conditions, which exclude microbial contamination of the samples from the environment. The composition of the microbiota of the samples was determined by microbiological and sanitary indicators, which include the number of mesophilic aerobic and facultatively anaerobic microorganisms (MAFAnM), micromycetes (mold fungi and yeast), bacteria of the group of Escherichia coli followed by the identification of opportunistic Escherichia coli and Staphylococcus; aureus pathogenic microorganisms, including salmonella, sulfite-reducing clostridia. Determination was carried out by sowing on special nutrient media with subsequent cultivation and characterization according to RTD [14, 15].

The above-mentioned agents of poisoning can cause serious diseases in decorative and singing birds, which can lead to death. Therefore, according to modern

requirements, the presence of these microorganisms in compound feed makes it possible to judge their sanitary condition.

IV. RESULTS

4.1. Optimizing the composition of feed for decorative and singing birds

The optimal composition of compound feed recipes was calculated using a software complex, which is based on the principles of calculating the minimum cost, taking into account the limitations of the input of each component and the nutritional value of the finished product using linear programming [16, 17].

In the table 4.1. gives recipes of compound feed for decorative and singing birds (budgies – №1 (CF №140-1), amadins – №2 (CF №140-1) and canaries – №3 (CF №140-1)) and their indicators quality.

Table 4.1. Composition of feed recipes for decorative and singing birds

Raw	CF №140-1	CF №140-2	CF №140-3
Peeled millet	43,0	24,0	29,3
Peeled oats	25,0	25,7	23,9
Sorgum	10,0	8,6	7,0
Wheat	–	10,0	6,0
Flax oil	3,0	5,3	4,0
Sunflower cake	7,2	8,1	–
Sunflower seeds	–	3,9	–
Sunflower meal	–	–	7,5
Rapeseed cake	–	–	4,5
Fodder yeast	1,0	3,0	3,0
Dry milk	–	–	2,7
Beets pulp	4,0	–	–
Apples pulp	4,0	4,0	–
Carrots pulp	–	–	4,0
Vineyards pulp	–	4,0	–
Pumpkin pulp	–	–	4,0
Monocalciumphosphate	0,4	1,4	1,3
Feed chalk	1,2	0,8	1,6
Kitchen salt	0,2	0,2	0,2
Premix	1,0	1,0	1,0
Everything	100,0	100,0	100,0
Quality indicators			
Exchange energy, kcal/100 r	272	287	310
Mass fraction of, %: crude protein	12,50	15,80	18,30
raw fat	5,40	6,50	8,10
raw ash	3,90	5,20	5,90
crude fiber	3,30	4,90	4,20
lysine	0,70	0,74	0,79
methionine	0,32	0,42	0,47
calcium	0,90	0,90	1,18
phosphorus	0,68	0,70	0,75
sodium	0,11	0,15	0,17

The calculated recipes correspond to the nutritional standards for decorative and singing birds.

4.2. Development of a method of production of compound feed for decorative and singing birds

We have proposed a method for the production of compound feed for decorative and singing birds in the form of extruded grits or a mixture of grits, which provides for the preparation of the initial components with subsequent dosing, mixing, extrusion, cooling, grinding and fractionation, with the aim of obtaining grits or a mixture of grits of different colors (dosing, mixing grits) and packaging.

Prepared (cleaned) grain raw materials (wheat, corn, etc.) that do not require husking and lump raw materials (cake, meal) are submitted for dosing. Oats and millet are cleaned of metallomagnetic impurities, husked and separated. Hulled millet and oats are served and dosage. In order to prevent regrinding, these types of raw materials are submitted for fractionation. The fine fraction passes through the sieve and is fed into the mixer, and the large fraction is cleaned of metallomagnetic impurities and subjected to grinding, and then enters the mixer.

Mineral, protein, non-traditional raw materials and premix come in packaged form. After grinding, the raw material is fed for dosing and, for the formation of a homogeneous mixture of a stable composition, mixing. At the exit from the mixer, we get loose compound feed, which we send to extrusion. Bulk compound feed is pre-controlled for the content of metal-magnetic impurities and served for mixing with pre-dosed wet components (fruit and vegetable pomace: it is provided that wet raw materials enter a hopper with a mixing device). The homogeneous mixture is submitted for extrusion at a temperature of 110-130°C and a pressure of 2-3 MPa.

The hot extrudate is cooled to a temperature that does not exceed the ambient temperature by more than 10°C. In order to obtain a grain, the extrudate is sent for grinding, the gap between the rolls is 0.4 – 0.5. In the machine for controlling the grain size, the upper sieves LC №30 and the lower one – LC № 10 are installed. After that, the small fractions (the passage of the lower sieve) are sent for reextrusion, the large fraction (the exit of the upper sieve) is submitted for grinding. The passage of the upper and the exit of the lower sieve is a finished grain, which is fed to the warehouse of finished products or to the hopper for the formation of a mixture of grains. Next, the extruded compound feed is sent to storage, packaging and release. To form a mixture of grains, different types of grains are dosed, mixed, packed and served for the release of finished products.

The appearance of fodder for decorative and singing birds is of great importance both for the bird and for its owners. Modern technologies of the feed industry can significantly change the natural color of products. Decorative and singing birds have well-developed organs of vision. It has the ability to distinguish colors – red, green, yellow, etc. Therefore, the technology provides for the introduction of natural dyes (extracts of red beets, carrots, pumpkins, apples, grapes of dark varieties) into the composition of fodder to achieve marketable and consumer appearance.

4.3. Characteristics of the quality indicators of compound feed for decorative and singing birds

In accordance with the developed recipes (Table 4.1) and improved technology for the production of compound feed for decorative and singing birds, test samples of compound feed in the form of extruded grain were obtained in laboratory conditions, in which physico-chemical and microbiological quality indicators were determined. The possibility of giving the extruded compound feed various shades – red (beet pulp), yellow (carrot and pumpkin pulp), purple (blue grape pulp) due to the inclusion of natural dyes – was investigated. We suggest introducing 8 % of wet components, which will allow to effectively moisten the starting mixture before extrusion due to the moisture contained in the starting raw materials.

Experimental samples of compound feed were obtained in laboratory conditions (№ 1, № 1a – compound feed before and after extrusion with the addition of beet pomace; № 2, № 2a – compound feed before and after extrusion with the addition of grape pomace; № 3, № 3a – compound feed before and after extrusion with the addition of carrot and pumpkin extracts) and organoleptic, physico-chemical and microbiological quality indicators were determined, which are listed in table. 4.2 and 4.3 and in fig. 4.2, 4.3 respectively.

As shown by the results (Table 4.2.), during the extrusion process, the moisture content decreases, which is positive from the point of view of further storage, as well as the volumetric weight decreases, other indicators change slightly.

In the extrusion process, protein denaturation occurs, which leads to an increase in the number of peptides and free amino acids. The result of this process is an increase in digestibility of proteins. Thus, extrusion processing, which causes starch gelatinization, destruction of cellulose-lignin complexes, and protein denaturation, significantly increases the feed value of mixtures of grain components. At the same time, the increased feed value, which is due to the high degree of digestibility and assimilation of nutrients, determines the high efficiency of the extruded mixture of grain components in the production of compound feed.

Table 4.2. Physical properties of test samples

Indicators	Indicators of experimental samples					
	For budgies CF №140-1		For amadins CF №140-2		For canaries CF №140-3	
	№1	№1a	№2	№2a	№3	№3a
Mass fraction of moisture, %	17,2	12,8	16,8	11,6	17,4	13,0
Volumetric mass, kg/m^3	714	610	722	558	728	575
Natural slope angle, grad	32	40	30	41	34	43
Fluidity, cm/s	9,1	10,8	8,9	10,5	9,0	10,3

In the process of extrusion, the components of compound feed are subjected to such processing stages as heat treatment, sterilization, disinfection, volume increase, grinding, mixing, dehydration, stabilization. As a result, there are significant changes in raw materials, starting with changes in physical properties, improvement of fodder qualities, increase of fodder value and ending with sterilization of compound feed.

As evidenced by the obtained data (Table 4.3.), according to organoleptic indicators, compound feed is characterized by an attractive appearance and smell

characteristic of a set of components and an increased content of nutrients and biologically active substances.

Table 4.3. Indicators of the quality of compound feed for decorative and singing birds

Indicators	Characteristic		
	For budgies CF №140-1	For amadins CF №140-2	For canaries CF №140-3
Organoleptic indicators			
Color	light pink	Light purple	yellow
Scent	Characteristic og the set of components included in the product, without extraneous odors		
Physical and chemical indicators			
Mass fraction of moisture, %	12,80	11,60	13,00
Mass fraction of crude protein, %	12,44	15,91	18,24
Mass fraction of crude fat, %	5,32	6,48	7,88
Mass fraction of crude fiber, %	3,41	3,89	3,94
Mass fraction of ash insoluble in hydrochloric acid, %	3,88	5,29	5,75
Mass fraction of calcium, %	0,90	0,90	1,11
Mass fraction of phosphorus, %	0,67	0,70	0,74

In the course of the conducted research (Table 4.4.), a comparison of experimental results of physical and chemical parameters of commercial feed and data printed on the packaging was also carried out. Where we can see that the data specified by the manufacturer do not correspond to reality, and are somewhat different.

Table 4.4. Physico-chemical indicators of the quality of industrial feed

Indicators	Industrial feed					
	Special One (for budgies)		Padovan (for exotic birds – amadines)		Nature (for canaries)	
	research	on the package	research	on the package	research	on the package
The mass fraction: moisture, %	12,40	13,00	10,90	13,00	10,50	13,00
crude protein, %	11,34	12,00	12,70	13,10	17,10	19,30
raw ash, %	3,42	3,40	3,75	2,80	5,20	4,40
crude fat, %	5,87	4,00	5,53	7,20	8,57	16,20
crude fiber, %	9,10	8,00	7,32	8,30	9,24	10,00
phosphorus, %	0,22	0,10	0,41	–	0,52	–
calcium, %	0,58	0,20	0,68	–	0,73	–

It is very important that compound feed is not only balanced in terms of nutrition, energy, and amino acid composition, but also meets the hygienic requirements for safe and high-quality feed. The purity of feed is the absence of pathogenic bacteria, mold and toxins in it, which pose a significant threat to the health decorative and singing birds.

It is very important that compound feed is not only balanced in terms of nutrition, energy, and amino acid composition, but also meets the hygienic requirements for safe

and high-quality feed. The purity of feed is the absence of pathogenic bacteria, mold and toxins in it, which pose a significant threat to the health and productivity of poultry.

The quality of fodder is determined by the quality of the initial components. Meanwhile, a large part of feed raw materials is exposed to risk factors that significantly affect the productivity and safety of livestock and poultry farming. Such risk factors include, first of all, mold, contamination of grain and feed during storage, and pathogenic microorganisms that, entering the body of animals with feed, multiply and cause disorders of the gastrointestinal tract.

To prevent the negative factors listed above, the extrusion process is provided for in this technology. So, the health of the bird depends not only on the quantity and quality of feed, but also on its sanitary quality. The sanitary quality of feed is the absence of pathogenic bacteria, mold and toxins in it, which pose a great threat to the health and productivity of animals. Therefore, the study of the qualitative and quantitative composition of the microflora is of great importance for the development and practical application of various processing methods in order to improve the stability and prolong the shelf life of compound feed for its further use in the compound feed industry.

The indicator of the number of mesophilic aerobic and facultatively anaerobic microorganisms (MAFAnM) is the most widespread microbiological indicator. It is used in the food and compound feed industry as an indicator of the sanitary state of production. Identification of the qualitative composition of the microflora is an indicator of safety, since the presence of pathogenic microorganisms or an increased content of opportunistic pathogens compared to the permissible norm can be the cause of poisoning.

The following types of compound feed were selected as objects of research: № 1, № 1a – compound feed before and after extrusion with the addition of beet pulp; № 2, № 2a – compound feed before and after extrusion with the addition of grape pomace; № 3, № 3a – compound feed before and after extrusion with the addition of carrot and pumpkin extracts; № 4 – TM "Special One" (for budgies); № 5 – TM "Padovan" (for exotic birds – amadines); № 6 – TM "Nature" (for canaries).

All samples in the amount of 1 kg were stored in paper bags for 3 months in the laboratory of the Department of Grain and Compound Feed Technology at a temperature of +6...+18 °C. The relative humidity of the air during the storage period fluctuated between 60...75 %. The insemination analysis of the samples was carried out before storage, as well as after 3 months of storage.

The analysis of the obtained results (Fig. 4.1.) showed that in the majority of samples, the component of the bacterial microflora is the non-spore-bearing bacillus Erwinia herbicola – a typical companion of grain compound feed when stored under standard conditions (representative of epiphytic microflora). The percentage of Erwinia herbicola bacteria from the total number of all bacteria in samples of non-extruded compound feed is about 70 %, the share of coliform bacteria and micrococci is 11 %. Among the spore-forming bacteria, bacterial groups Bacillus subtilis – licheniformis were found, the relative number of which was 1.4 % of the total number of bacteria in all samples. Among the micromycetes, field mold fungi such as:

Cladosporium, Alternaria and a small number of unidentified fungi were found before storage.

As research has shown, no growth of microorganisms was detected in all samples. On the contrary, the initial number of bacteria and micromycetes decreased during storage. The decrease occurred due to the death of non-spore-forming bacteria Erwinia herbicola, which is natural. Due to the fact that Erwinia herbicola is dying out, the composition of the bacterial microflora is regrouping – the relative content of non-spore-forming forms and micrococci decreases, and spore-forming ones increases. This is a consequence of the unequal degree of survival of different bacteria.

A different picture is observed when analyzing micromycetes (Fig. 4.2.). Micromycetes practically did not develop, but a change in their qualitative composition was observed. The number of field molds of the genera Alternaria, Cladosporium and others has significantly decreased. Mold fungi of the genera Aspergillus and Penicillium became permanent representatives of the fungal microflora of the studied compound feeds.

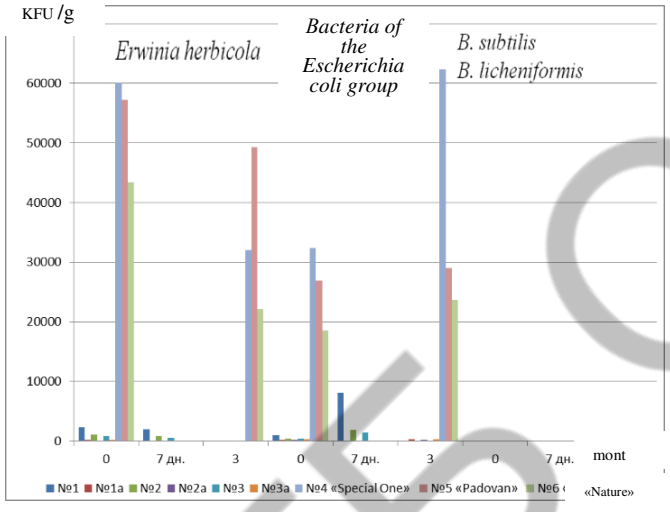

Fig. 4.1. Change in the number of bacteria during storage: № 1 – loose compound feed for extrusion; № 1a – compound feed after extrusion; №2 – loose compound feed for extrusion; № 2a – compound feed after extrusion; № 3 – loose compound feed for extrusion; №3a – compound feed after extrusion; № 4 – TM "Special One" (for budgies); № 5 – TM "Padovan" (for exotic birds - amadines); № 6 – TM "Nature" (for canaries)

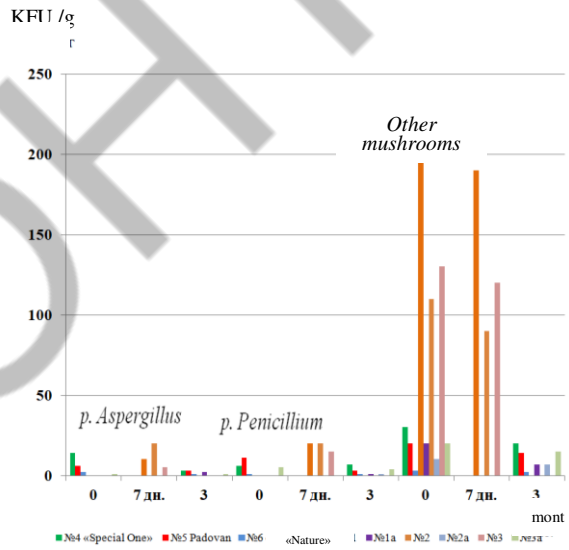

Fig. 4.2. Change in the number of micromycetes during storage: № 1 – loose compound feed for extrusion; № 1a – compound feed after extrusion; № 2 – loose compound feed for extrusion; № 2a – compound feed after extrusion; № 3 – loose compound feed for extrusion; № 3a – compound feed after extrusion; № 4 – TM "Special One" (for budgies); № 5 – TM "Padovan" (for exotic birds - amadines); № 6 – TM "Nature" (for canaries)

Escherichia coli, salmonella, staphylococcus, proteus, and sulfide-reducing clostridia were not detected in all tested samples of compound feed. This testifies to the provision of appropriate standards of sanitary and hygienic conditions during the production and storage of compound feed.

V. CONCLUSIONS

The following conclusions were drawn on the basis of the conducted research:

1. In order to meet the feed needs of decorative and singing birds when they are kept in captivity, one of the most effective methods is the creation of complete ration compound feed by using innovative technologies (in the form of grits or a mixture of grits obtained by extrusion). This will make it possible to satisfy both behavioral and feed needs.

2. Taking into account the market analysis, as well as based on the study and generalization of literary and Internet sources, we proposed a classification of feed for decorative and singing birds by bird species, purpose, form of release, price, physiological features and age, as well as by type of packaging.

3. A method for the production of compound feed for decorative and singing birds in the form of extruded grits or a mixture of grits is proposed, which provides for the preparation of the initial components with subsequent dosing, mixing, extrusion, cooling, grinding and fractionation, with the aim of obtaining grits or a mixture of grits of different colors (dosing, mixing of grains) and packaging.

4. The quality of experimental samples and industrially produced feeds was evaluated according to organoleptic, physico-chemical and microbiological indicators and it was established that these combined feeds meet the needs of poultry in terms of the main nutritional indicators and are not inferior to industrial analogues.

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PRODUCTION TECHNOLOGY OF "BORODINSKY" BREAD IN THE TERMS OF "TERNOVSKY HLIBSAVOD" LLC

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Abstract. *Bread production technology is one of the main issues today, as bread is the main component of human nutrition. The technology of production of "Borodynskyi" bread by various methods of preparation was studied. According to the organoleptic indicators, namely: the condition of the crumb, color, structure, porosity, aroma and taste, the best indicators were the bread "Borodynskyi", made according to a modern recipe. It was established that the production of "Borodinsky" bread was more efficient with the modern recipe.*

Key words*: technology, bread, flour, assessment, quality, recipe.*

I. INTRODUCTION

Bread is one of the most common flour products in the daily human diet. For its preparation, they use the knowledge of scientists, engineers and technologists who are engaged in breeding new varieties of grain, follow techniques, create new recipes and monitor production.

Since ancient times, making rye bread has been considered a work of art. The basis for the production of rye bread was special sourdough. The sourdough recipe was passed down from generation to generation. Sourdough was considered leavened dough, which remained from the previous baking of bread. The taste and aroma of the bread depended on the quality of the leaven.

Nowadays, there are a large number of types of bread, which are made both at home and in large factories. Therefore, taking into account the variety of bread products, it is advisable to analyze the technology of production of bakery products.

II. ANALYTICAL REVIEW OF LITERATURE

2.1. History of "Borodinsky" bread

There are many legends about the origin of "Borodyn" bread. The most common version is the story about Margarita Tuchkova, abbess of Spaso-Borodino Monastery [2].

She was the wife of Alexander Tuchkov, a Russian general who died in the Battle of Borodino in 1812. After the death of her husband, Margarita Tuchkova (Naryshkina) became a nun and founded this monastery. It was supposedly there that they started baking the Borodino bread we know today. This is a beautiful story, but the problem is that until the 1930s, the word "Borodinsky" in relation to bread is not found anywhere in the sources [11].

The recipe for modern Borodino bread was specially developed in 1933 by the Moscow Baking Trust. The recipe for Borodino bread was replenished with one ingredient - coriander. Therefore, currently the recipe for Borodino bread includes: salt, yeast, sugar, rye malt, ordinary rye flour, molasses and coriander [3, 9].

"Borodinsky" bread has a smooth surface that does not contain cracks and is sprinkled with coriander, anise or cumin on top. The shape of the bread resembles an oblong loaf, with rounded blunt ends. The custard should be well baked, not sticky, elastic and slightly moist to the touch. The taste is sweet and sour, quite pleasant without signs of bitterness and extraneous crunch and taste on the teeth from mineral impurities. This is the bread of the highest quality [10].

2.2 Characteristics of raw materials for bread production

The main raw materials needed to make the dough are: flour, water, yeast or sourdough, salt. Additional raw materials include dairy products and milk, sugar, molasses, egg products, fats, vitamins, seeds of essential oil plants: vanillin, cinnamon, and others [7].

The basis of production is wheat (higher, first, second grade and upholstery) and rye (husked, seeded and upholstery) flour, sometimes corn or barley is added. For every 100 kg of flour, from 30 to 75 kg of water is used, depending on the grade and moisture content of the flour, the bread recipe, etc. [5, 11].

Different types of yeast are also used, which, when added to the dough, form carbon dioxide bubbles, as a result of which the structure of the bread becomes porous and acquires a characteristic smell and taste [1].

Water for cooking must meet sanitary standards in terms of bacteria content [5].

Salt must meet the requirements of the standard (for food purposes). For further use, it must be dissolved and filtered. Salt solution is added to the dough in the amount of 1.4-2.7% of the mass of flour, it plays a significant role in preventing the weakening of gluten [5].

Sugar is added to improve the technological properties of the dough. Put in the dough in a dissolved form [5, 9].

Egg (egg powder) and dairy products (dry milk, cheese, sour cream, whey) enrich products with complete proteins, fats, minerals and other substances, give them a bright taste and slow down the aging process [9].

With the addition of fats, the nutritional value and taste of bread increases, and in a small amount, its quality and shelf life improve. Liquid fats are filtered before being added to the dough, and solid fats are melted in advance [10].

Raisins, poppy seeds, spices, honey, fruit and vegetable juices, purees, pastes and some other types of raw materials improve the biological value of products, their appearance, taste and smell [4, 10].

2.3. Technological process of bread production

Bread production consists of five stages: preparation of raw materials, preparation and processing of dough, baking, cooling and storage of bread [1, 5].

Preparation of raw materials consists of the following stages: preparation of flour, production of yeast suspension and preparation of salt solution [6].

First, flour is prepared: it is mixed and sifted, magnetic impurities are separated. Then the water is heated to a certain temperature, salt is dissolved in it, the salt solution is filtered and allowed to settle. Yeast is dissolved in water, fats are cleaned and melted, and other additives are prepared [2, 7].

Dough preparation includes the following technological operations: dough kneading, its fermentation, dough kneading, fermentation, kneading the dough. The

dough is kneaded for 3-6 minutes until a homogeneous mass is formed. The duration of the fermentation of the foam is different: 1-3 hours [8].

Then all components of raw materials are dosed according to the recipe and mixed. Kneading the dough lasts 4-9 minutes. During the kneading of the dough and dough, the fermentation process begins. Fermentation temperature is 27-30°C [6, 8].

Fermented dough is processed in the following sequence: the dough is rolled and divided into pieces, each of them is given a rounded shape, the dough is allowed to stand, and then shaped [6].

With the help of rounding machines, the resulting pieces of dough are rounded to the shape of a layer. After that, the dough is left to rest for 5-8 minutes for proofing. After giving the semi-finished product the desired shape, it is sent for final curing, which lasts from 20 to 125 minutes. Formed pieces of dough are laid out on a belt conveyor, where the dough is finally proofed, and then the workpieces are delivered to the oven for baking by the same conveyor [11].

Baking is the last stage of bread production, which is carried out in bakery ovens of various designs [1, 10].

The product is baked at a temperature of 210 to 260°C for 7-14 to 50-60 minutes. Modes of baking bread depends on the type of products, on the type of flour, the moisture content of the dough, the mass and shape of the products, the method of baking, etc. [2, 5].

Hot bread requires care, because it can crumple, which worsens the appearance and porous structure of the crumb. Therefore, after baking bread before sending it to the retail network, it is transferred to the bread storage for cooling, and sold no earlier than three hours after baking [4, 8].

III. OBJECT, SUBJECT AND METHODS OF RESEARCH

Three recipes were used in the production of "Borodinsky" bread: the first recipe, which was known since 1929, the second - more modern, and the third - according to DSTU [7].

Recipe of 1929. Ingredients: upholstery rye flour, 2nd grade wheat flour, fermented rye malt, fresh yeast, salt, maltose molasses, sugar, coriander, water. For sourdough: mature rye sourdough, water, rye upholstery flour, a pinch (0.1 g) of instant yeast. For brewing: flour, fermented (red) malt, water. For the dough: brew, sourdough starter, water, rye flour. Dough: whole dough, salt, maltose molasses, sugar, water, wheat flour of the 2nd grade, rye flour, ground coriander [1].

Preparation: Sourdough. Dilute 45 grams of active rye sourdough with the required amount of water to a foamy mass, add rye flour, roll into a dense layer and leave for 5 hours to mature at 30°C [11].

Brewing Mix flour and malt, dilute them to 100 gr. of warm water, pour another 120 g into the resulting mixture. boiling water and stir. Cover with a lid and leave for saccharification of flour starch for 5-6 hours at 63-65°C. The mass will become much thinner and sweeter in taste, and the color will be chocolate [11].

Sponge. Mix the brew-water-leaven well. Add flour to the resulting mixture. Leave under the film for fermentation until the maximum yield (2-3 hours) at 32°C [11].

Dough. Dissolve salt-sugar-molasses in a small amount of water. Add the resulting mixture to the steam and stir. Combine rye and wheat flour and add steam to them. Knead until smooth. Leave to ripen under the lid or film for 45-60 minutes. Put the finished dough on a wet table and form a loaf with wet hands [11].

It should be well distributed in the form, form a semicircular "cap" and leave under the film for 45 minutes. During this time, the dough will rise to the edges of the form. By the time the dough rises, the oven should be preheated to the maximum temperature (260°C) [11].

Before putting it in the oven, you need to coat the bread with flour (flour + water) and sprinkle with coriander or cumin. Bake without steam for 15 minutes at the maximum temperature, then ventilate the oven, reduce the temperature to 150°C and bake for another 1.5-2 hours. Immediately smear the finished bread with jelly and leave it on a wire rack to cool [11].

A modern recipe. Ingredients: rye flour, wheat, malt, warm water, yeast, sugar, salt, coriander, cumin. Preparation: dissolve yeast and sugar in water, set aside for 15 minutes. You need to leave it until the yeast is completely dissolved. Pour malt, flour, the rest of the water, mix well. Add salt, coriander, cumin, and knead the dough. Cover with a lid and leave in a warm place for 1-2 hours. When the dough is ready, form a bun and set aside for another 2 hours. Then the blanks are placed in the oven for 35 minutes at 180°C [10].

Recipe for DSTU. Ingredients: rye flour, wheat, malt, water, hot water, honey, coriander, rye sourdough, sugar, salt, coriander in grains [10].

Preparation: Mix rye flour, malt, ground coriander. Pour boiling water, close the container well and leave for 2 hours in a warm place. Dilute salt, sugar, honey with warm water. Mix with leaven, water, two types of flour. Knead the dough to a thick consistency. Lubricate the container with oil, put the dough and cover with a lid. Leave for 3-4 hours. Heat the oven to 220 degrees, grease the dough with water, sprinkle with coriander seeds and bake for 20 minutes. Lower the temperature to 200°C and bake for another 60 minutes. The finished product should be covered and left to ripen for an hour [10, 11].

The preparation of "Borodinsky" bread according to three recipes shows that they differ in cooking time - the first recipe takes 12 hours, the second - 5 hours, and the third - 8 hours [9].

To obtain the required amount of products, the mass of dry substances and moisture in raw materials are calculated [3].

$$G_{\text{ср}} = G_{\text{с}} \cdot \frac{a}{100} \quad (1)$$

Where $G_{\text{ср}}$ – mass of dry substances in raw materials, kg;

$G_{\text{с}}$ – mass of raw material, kg;

a – content of dry substances in raw materials, % [3].

The amount of moisture in raw materials can be calculated in two ways [7]

$$G_{\text{вол}} = G_{\text{с}} - G_{\text{ср}} \quad (2)$$

Or

$$G_{\text{вол}} = G_{\text{с}} \cdot \frac{W}{100} \quad (3)$$

Where W - raw material moisture, % [7].

Salt and sugar are usually used in the form of solutions for uniform distribution throughout the mass of the dough [3, 7].

The amount of salt or sugar solution is calculated according to the formula [3]: $G_{\text{роз}} = \frac{G^{\text{б}}_{\text{заг}} \cdot m}{c}$ (4)

Where $G_{\text{роз}}$ – amount of solution, kg;

c – concentration of salt (sugar) in the solution, kg per 100 kg of solution [7].

The amount of water added to the dough with a solution of salt or sugar is calculated according to the formula [7]:

$$G_{\text{в}} = V \cdot \rho - G_{\text{с}} \quad (5)$$

Where V – volume of saline solution, l;

ρ – density of salt solution, kg/l;

$G_{\text{с}}$ – mass of dry salt (sugar), kg [3, 7].

IV. WORK RESULTS

4.1. Equipment for making bread

The following equipment was used for the production of bakery products: flour sifter, melting device, leavening tank, dough kneading machine, dough dividing machine, dough rounder, dough pre-exposure chambers, dough rolling machine, bakery oven, bread slicer, packaging machine, steam generator.

The flour sifter was used at the enterprise to automate the dough preparation process, to significantly improve the quality and taste of bakery and confectionery products. Its main purpose is the mechanized separation of flour from metal impurities and foreign particles, cleaning, fluffing, filling with oxygen.

Flour sifters are divided into vibrating (Pic. 1) and centrifugal (Pic. 2) according to productivity and the type of sieving.

The flour sifter of the vibrating type works on the principle of vibration of the sieve, into which the flour is fed in portions, sifted and enters the prepared containers. In a centrifugal flour sifter, sifting is carried out due to the rotation of the drum.

Pic. 1. Vibrating flour sifter

Pic. 2.. Centrifugal flour sifter

The melting apparatus (Pic. 3) was used to melt blocks of butter, margarine, and fats. Schematically, the technological process of melting the product was carried out as follows. The product in blocks was placed on the surface of a grate heated by water. The product melted and accumulated in the body bath, from where, as it filled, it was drained or pumped out through a faucet.

Pic. 3. Melting machine

The sourdough tank (Pic. 4) is intended for preparing sourdough. It works as follows: the necessary ingredients were placed in the drum and the lid was closed. With the help of the control panel, everything was well mixed, the required temperature was set and the raw materials were left until they were completely ready. The starter tank has a lid that helps prevent dust and other foreign objects from getting into the starter.

Pic. 4. Fermentation tank

The dough mixer (Pic. 5) was used for automatic dough kneading. The principle of operation: the dough components were poured into the bowl of the apparatus and

the apparatus was started. Using the timer, it was possible to quickly change the kneading speed and bring the dough to the desired consistency. The bowl is removed from the device, which made it easier to transport the dough.

Pic. 5. Dough kneading machine

After mixing the dough with all the ingredients, it was necessary to divide it into the required number of blanks of the same weight. For this purpose, a dough dividing machine was used (Pic. 6). The finished dough was loaded into the machine, and at the exit, the dough was cut into portions.

A dough rounder (Pic. 7) was used to give the blanks a rounded shape. The dough, already cut into portions, was put into the machine one by one, after which the already rounded workpiece was received.

Chambers for preliminary aging of the dough (Pic. 8) were used to create optimal conditions for fermentation of the dough. After the dough rounder, the blanks were sent to the pre-exposure chambers and remained there for a certain time.

Pic. 6. Dough dividing machine

Pic. 7. Dough rounder

Pic. 8. Dough pre-exposure chambers

A dough rolling machine (Pic. 9) was used to give the rounded blanks the correct cylindrical shape. Thanks to the process of rolling the dough, large gas bubbles break up into many small bubbles that are evenly distributed. This contributed to the formation of a porous, uniform and airy pulp.

Pic. 9. Dough rolling machine

The bakery oven (Pic. 10, 11) was used to bake a wide range of bread and bakery products.

Pic. 10. Bakery oven, view from the inside

Pic. 11. Bakery oven, exterior view

The bread cutter was used at the enterprise to cut ready-made bread products into pieces of a given thickness. Enterprises can use three types of bread cutters: automatic

(Pic. 12), semi-automatic (Pic. 13) and manual (Pic. 14). But for greater productivity, automatic ones are more often used.

Pic. 12. The bread slicer is automatic

Pic. 13. Semi-automatic bread cutter

Pic. 14. Manual bread cutter

The packaging machine (Pic. 15) was intended for packaging ready-made bread and bakery products, whole or sliced.

The steam generator (Pic. 16) was used at a bakery to maintain a certain percentage of dough moisture during its settling. This is necessary so that a dry crust does not appear on the raw dough.

Pic. 15. Packing machine

Pic. 16. Steam generator

4.2. Bread making technologies

Depending on the type of bread, different cooking technologies are used. So, for example, the following cooking technology was used for "Borodinsky" bread. Among the ingredients, we used (based on one loaf) rye flour - 1 tbsp. l., wheat - 300 g, malt - 2 tbsp. l., warm water - 300 ml., yeast - 1.5 tsp., sugar - 1 tbsp. l., salt - 1.5 tsp, coriander - 1.5-2 tsp, cumin - 1.5 tsp.

Preparation process: first, 1.5 tsp was diluted in 100 ml of water. yeast and 1 tbsp. l. sugar Mix thoroughly and leave the mixture for 10 minutes at room temperature. After the yeast has worked, 1 tbsp was poured into the mixture. l. rye flour, 300 g of wheat, 2 tbsp. l. malt, poured the rest of the water and mixed well. Then added 1.5 tsp. salt, 1.5-2 tsp. coriander, 1.5 tsp. cumin and knead the dough. Covered with a lid and left the dough in a warm place for 1.5-2 hours. When the dough was ready, it was taken out of the container and formed into a loaf. The workpiece was placed in a baking dish and left for another 1.5 hours. After the second stand, the form with the dough was sent to the oven for 30 minutes at 180°C. After baking, the form with the finished bread was removed from the oven and left to cool.

4.3. Calculations of the use of raw materials for "Borodinsky" bread

Calculations of the mass of dry substances and moisture in 50 kg of flour with a moisture content of 12.5%:

The content of dry substances in raw materials:

$$a = 100 - 12{,}5 = 87{,}5\%$$

Mass of dry matter:

$$G_{\text{ср}} = 50 \cdot \frac{87{,}5}{100} = 43{,}75 \text{ кг.}$$

Mass of moisture:

$$G_{\text{вол}} = 50 - 43{,}75 = 6{,}25 \text{ кг}$$

Determination of the maximum amount of flour in a vat with a capacity of 350 liters:

$$G_{\text{деж}} = 350 \cdot \frac{38}{100} = 133 \text{ кг.}$$

Determination of the amount of flour in the dough. 80 kg of dough with a moisture content of 50% is taken for kneading the dough:

$$G_{\text{оп}}^{\text{б}} = 80 \cdot \frac{(100 - 50)}{100 - 14{,}5} = 46{,}8$$

The amount of flour for kneading the dough:

$$G_{\text{т}}^{\text{зам}} = 125 - 46{,}8 = 78{,}2 \text{ кг}$$

Since the dough consists not only of water and flour, but also of salt and yeast,

you need to determine how much flour will be needed for 100 kg of dough:

$$G_{\text{т}}^{\text{б}} = \frac{100\,(100-46)-1{,}0\,(100-3{,}5)-0{,}3(100-75)}{100-14{,}5} = 61{,}9 \text{ кг.}$$

Consumption of dry salt for dough kneading:

$$G_{\text{с}} = 80 \cdot \frac{1}{100} = 0{,}8 \text{ кг.}$$

Sugar costs for dough kneading:

$$G_{\text{с}} = 80 \cdot \frac{1}{100} = 0{,}8 \text{ кг.}$$

Costs of coriander and cumin for dough kneading:

$$G_{\text{с}} = 80 \cdot \frac{0{,}5}{100} = 0{,}4 \text{ кг.}$$

We determine the required amount of salt and sugar solutions for kneading 80 kg of dough:

$$G_{\text{роз.с}} = 50 \cdot \frac{1{,}5}{25} = 3 \text{ кг;}$$

$$G_{\text{роз.ц}} = 50 \cdot \frac{5}{50} = 5 \text{ к.}$$

Calculation of yeast suspension:

$$G_{\text{др. сус}} = \frac{150 \cdot 1 \cdot (1+3)}{100} = 6 \text{ кг}$$

Determination of the mass of the dough:

$$G_{\text{т}} = \frac{93{,}62 \cdot 100}{100-43{,}5} = 165{,}7 \text{ кг.}$$

Determining the required amount of water for kneading the dough:

$$G_{\text{в}} = 165{,}7 - 122{,}4 = 43{,}3 \text{ кг.}$$

4.4. Assessment of bread quality

The consumer value of any food product and the demand for it are regulated by its quality. The quality of bread is formed by a number of factors, which include the quality of raw materials, compliance with the technological process and the safety of technological equipment, the quality of the work of producers, the quality of storage, transportation and sale of products, as well as the quality of product consumption, that is, the quality of production and the quality of post-production conditions of existence of products. Violation of the specified or one of these factors causes the receipt of lower quality, or even substandard products.

To ensure the quality of products, the enterprise controls the quality of raw materials, semi-finished products, compliance with technological process parameters, finished products before their sale.

The main organoleptic indicators of the quality of bread are: appearance, shape, color, condition of the surface and crumb. The physico-chemical parameters include: moisture, acidity, porosity, sugar and fat content (for products that contain sugar and fat).

The organoleptic method of analysis was used to determine the quality indicators of "Borodinsky" bread made according to three recipes. From the organoleptic indicators, the following were determined: appearance, shape of the bread, its color,

condition of the surface and crumb, character of porosity, taste and smell.

The organoleptic indicators of the quality of "Borodinsky" bread were characterized as follows: color "pale", "golden yellow", "light brown", "dark brown"; crust condition - "smooth", "uneven", "cracked", "undermined"; color of pulp - "white", "gray", "dark"; porosity - "uniform", "uneven", "shallow", "medium", "large", "thick-walled"; the elasticity of the pulp is "good", "average" or "poor", that is, the pulp is elastic, not sufficiently elastic or inelastic (Table 1).

Table 1. Results of organoleptic evaluation of bread

Indexes	Norms established by the standard	Actually the state of quality	Conclusion
Form	Oblong-square or oblong-oval	Oblong-square	Meets the requirements
Surface condition	Cracks with a height of no more than 1 cm are allowed	Minor crust cracks (0.3-0.5 cm wide)	Meets the requirements
The state of the pulp	Baked, not sticky	Baked, not sticky	Meets the requirements
Color	From light gray to dark brown	Light brown	Meets the requirements
Structure	Without lumps and traces of poor mixing	There are no lumps, the dough is well mixed	Meets the requirements
Character of porosity	Developed, without voids and seals. Not uniform is allowed	The porosity is uniform, with minor compactions	Meets the requirements
Aroma	Characteristic of this type of products, without extraneous smell	Characteristic of this type of products, without extraneous smell	Meets the requirements
Taste	Characteristic of this type of products, without extraneous aftertaste	Characteristic of this type of products, without extraneous aftertaste	Meets the requirements

Improvement of product quality assessment methods should be carried out by introducing objective instrumental and chemical methods.

4.5. Economic efficiency of research

Economic efficiency means the effectiveness of the economic system, expressed in the ratio of useful final results of its operation to the resources spent.

An economically justified determination of the amount of profit is of great importance for the enterprise, it allows to correctly assess its financial resources, the amount of payments to the budget, the possibility of expanded reproduction and material stimulation of employees. In addition, the implementation of the dividend policy of the joint-stock company also depends on the amount of profit.

At the same time, the economic and financial analysis of the results of the organization's economic activity allows for the development of a specific strategy and tactics for its development, identification and assessment of reserves for the growth of profit and profitability and ways of mobilizing them. This also applies to baking as a branch of agriculture.

Bread and bakery products have always been and are one of the most consumed

products. But at present, the economic efficiency of the enterprises of the bakery industry is quite low, as evidenced by the decline in the production of bread and bakery products.

Also, due to the increase in prices for raw materials, the average price of bread increased by an average of 15%. This can be seen on the example of the increase in prices for "Borodinsky" bread for 2021-2022, in particular in various grocery stores in the city of Mykolaiv (Table 2).

Table 2. Dynamics of the cost of "Borodinsky" bread in retail chains.

Grocery store	The cost of "Borodinsky" bread (0.5 kg), UAH	
	Year 2021	Year 2022
ATB	16	19
Tavria V	18	20
Silpo	21	26
Doyarushka	17	20
Velmart	20	25
Mida	14	16
Novus	24	28

Some of the actual directions for increasing the economic efficiency of activity at the enterprise level in the bakery industry are:

• technical re-equipment of the enterprise – this means replacing old equipment with new, more modern ones, or complete automation of the preparation process, starting from the supply of raw materials and ending with the packaging of the finished product;

• intensification of innovative activity - this can be done with the help of the release of new products or by reducing the cost of existing products by replacing certain raw materials with a cheaper analogue or removing a certain component from the recipe;

• increasing labor productivity - this can be done by improving work methods, motivating employees or coordinating management processes.

V. CONCLUSIONS

For the production of "Borodinsky" bread, modern powerful equipment, fast packaging and transportation to the places of sale of the product are used.

It has been proven that "Borodinsky" bread is made without the use of GMOs, but with the introduction of leavens.

According to organoleptic indicators: the condition of the crumb, color, structure, porosity, aroma and taste, the advantage was given to "Borodinsky" bread, which is made according to a modern recipe.

During the production of "Borodinsky" bread, it was established that the most effective for production is a modern bread recipe.

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SEMI-FINISHED PRODUCT TECHNOLOGY FOR FROZEN DESSERTS

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Abstract. *The analysis of literary sources showed that the creation of products with reduced glycemic load and functional properties are new ways of improving the technologies of ice cream and frozen desserts. It has been proven that lowering the glycemic index is possible by replacing sugar with fructose or other sugar substitutes. Provision of functional (prebiotic) properties is expedient to be carried out at the expense of the introduction of lactulose. It has been proven that the rational formulation of the mixture from the point of view of the properties of the obtained semi-finished product should be considered formulations based on serum with the content of lactulose 1%, fructose 11%, stabilizer 0.4%, dry milk 8%. The optimal pasteurization process for the semi-finished product was determined - at a temperature of 80...82°C for (5.8...6.2)×60^{-1}s. The whipping ability was 70±1.8%, the ability to form stable foams was 80±2.0%. A technological scheme for obtaining a semi-finished product for frozen desserts based on whey with lactulose, fructose, stabilizer was developed. A set of data characterizing the quality of the developed semi-finished product was obtained, and its high nutritional and biological value was proven. Modes and terms of storage of semi-finished products are substantiated: temperature -4...6°C, no more than 3 months, in unsealed form – no more than 48 hours.*

Keywords: *semi-finished product, frozen desserts, prebiotic, fructose, lactulose, cheese whey.*

I. INTRODUCTION

Production of ice cream and frozen desserts is one of the most promising segments of the dairy industry. Ice cream is an affordable complete food product with high digestibility and a valuable source of important functional nutrients. The technologies of frozen dessert products allow adding additives that play the role of functional and technological components to their composition. This makes it possible to expand the range of targeted products for various types of food, taking into account age, individual needs, national and social requests [1].

The analysis of modern nutrition shows its inconsistency with the requirements of nutrition due to insufficient consumption of proteins, minerals, vitamins and an overload of saturated fats and easily digestible carbohydrates. The modern diet needs to improve the recipes of frozen products according to priority directions: increasing the content of functional ingredients (sulfur-containing amino acids, dietary fibers) against the background of reducing the content of fatty components and reducing the sugar content. The modern approach to the creation of food products is definitely related to the use of the concept of glycemic indices and glycemic load [2].

It is the presence of simple sugars in ice cream that determines its high glycemic index, which forces consumers to significantly limit its consumption, and patients with

diabetes, cardiovascular diseases or obesity to exclude ice cream from their diets altogether. Solving this problem is possible in two ways: making unsweetened ice cream or using sweeteners or fructose instead of sugar [3]. By the way, unsweetened ice cream is extremely popular in European countries and in Japan, where they make ice cream with the flavors of meat, seafood (shrimp, octopus, cuttlefish), seaweed, beer, as well as vegetable ice cream - tomato, pumpkin, carrot, garlic, onion, cucumber with spicy herbs, beet, potato, etc. However, such ice cream is not popular in Ukraine and is not produced by any manufacturer. Ukrainians perceive ice cream exclusively as a dessert. Therefore, today the problem of lowering the glycemic index of ice cream can only be solved by using sweeteners or fructose [4]. Thus, the scientific and practical task of creating a new generation of frozen desserts with reduced glycemic load, enriched with functional ingredients, is relevant and timely.

The purpose of this work is the scientific substantiation and development of the semi-finished product technology for frozen desserts based on whey with lactulose and fructose.

In accordance with the set goal, the following tasks were to be solved:

- determine the rational ratio of components in the semi-finished product;
- to study the complex of physico-chemical and technological properties, nutritional and biological value of the semi-finished product;
- draw up regulatory documentation, determine its consumer characteristics and main areas of use in the production of culinary products;
- to develop recipes and technologies of ice cream and dessert products.

II. LITERATURE ANALYSIS

2.1. Ways to improve the technologies of soft ice cream and frozen desserts

Today, the food industry is rapidly developing new product platforms and bringing new product categories to the market. The main goal of this activity is the economic growth of economic entities, therefore, most types of food products contain a large number of food additives that create the identical natural structure, taste, color of the product, etc. But the majority of food additives have either a synthetic origin or are subjected to deep physico-chemical influence during production, which determines their harmful effect on human health.

In the segment of frozen dessert products, the distinguishing feature of which is the multi-stage production process and the need to use special equipment, all modern technologies involve the use of foam and structure-forming food additives for the formation of a whipped and stable structure [5].

Experts in the dairy industry note that the direction of creating low-calorie ice cream through the use of vegetable fat substitutes is quite developed, however, numerous medical studies have proven the harm of such products to health, so more and more consumers refuse such a dessert and prefer more healthy products. However, unlike the countries of Europe, America and Asia, this segment of the frozen products market is unfilled in Ukraine. Therefore, technologists face the urgent problem of developing new technologies and adjusting the recipe composition of ice cream and frozen desserts in order to increase the content of protein and dietary fiber [6] against

the background of reducing the amount of fat and sugar [7].

A promising way to solve this problem is to use low-fat dairy secondary raw materials as a basis for ice cream, such as casein, whey, sour milk cheese, low-fat goat milk, concentrated milk protein, etc. [8].

One of the ways to increase the dietary fiber content is the use of vegetable (pumpkin, carrot, tomato), fruit (apple, quince, etc.) and berry purees as a filler for dairy products or as a base for ice cream [9]. At the same time, the researchers note that due to the content of pectin substances and fiber, fruit and berry and vegetable purees play the role of a moisture-retaining and emulsifying component in food systems, and the presence of easily digestible sugars (mainly fructose and glucose) allow to exclude or limit the amount of sugar [10].

A new approach to the use of unused natural properties of raw materials can make it possible to maximize their functional properties, which will increase the economic efficiency of technologies by reducing the use of food additives and sugar, as well as increase the nutritional and biological value of finished products.

2.2. Analysis of modern ice cream technologies

The analysis of the diet of Ukrainian citizens shows its non-compliance with the requirements of nutrition due to insufficient consumption of proteins, minerals, vitamins and an overload of simple carbohydrates. The modern diet requires improvement in the production of products in priority directions: functional and low-fat food products, with reduced sugar content or without sugar and with a low glycemic index [11]. The assortment of ice cream with sugar substitutes in Ukraine is insignificant, production volumes are limited to the production of ice cream with xylitol and sorbitol. The modern approach to the creation of food products is connected, in particular, with the use of the concept of glycemic indices and glycemic load.

Consumer demand for healthier products is driving down the sugar content in dairy products. Sugar plays an important role in ice cream not only for flavor, but also for texture, color and viscosity. There are natural and artificial sweeteners designed to reduce sugar levels [12]. However, there is little information on the effect of high-intensity sweeteners and fat substitutes on the perception of sensory properties of ice cream [13].

In recent years, in many scientific works of Ukrainian and foreign scientists (A.M. Dorohovych, V.F. Dotsenko, N.A. Didukh, D. Richarda), considerable attention has been paid to the production of food products with sugar substitutes.

It is proposed to solve the problem of reducing the glycemic index of ice cream by using sugar substitutes (stevia, lactite, sorbitol, aspartame) [14] and fructose [15].

The technology of ice cream with fructose, prebiotic and sour milk cheese was developed, which ensure the production of high-quality ice cream with reduced glycemia and improved nutritional and biological value [16]. It was found that the introduction of sugar substitutes – fructose and sorbitol into ice cream increases the content of bound moisture by 4.2%, which improves the structure and consistency of ice cream and reduces the glycemic index of the finished product by 8.75%.

At the current stage, many researchers will develop ice cream with prebiotics (usually inulin or other non-starch oligosaccharides) [17] or probiotics [18, 19].

The effect of adding probiotics on the quality indicators of ice cream was studied [20]. According to the authors, the whipped texture of ice cream was found to improve the gastrointestinal tolerance of probiotics compared to natural yogurts and fruit yogurts, as evidenced by an in vitro stomach survival study of probiotics (B. animalis). In addition, it was determined that the addition of B. animalis decreased the pH, but did not affect the physicochemical properties and melting of ice cream, and obtained good sensory evaluations and satisfactory probiotic viability [21].

Currently, a promising direction is the use of dairy processing products in the production of ice cream - buttermilk, whey, sour milk cheese, yogurt [22, 23], which is expedient from the point of view of manufacturability, high nutritional value, and rational use of by-products of dairy production.

Conclusions: Considering the above, it can be concluded that dairy technologists are conducting quite intensive scientific work to find new ways to improve recipes and technologies of ice cream and frozen desserts in the direction of creating products with a reduced glycemic index. Thus, the scientific substantiation and development of the technology of frozen dessert products with a low glycemic index based on low-fat dairy raw materials is relevant today.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The object of research is the technology of a semi-finished product for frozen desserts based on whey with lactulose and fructose.

The subject of the study is whey, fructose, lactulose, model food systems containing whey, fructose and lactose, semi-finished products for frozen desserts.

Research methods are physicochemical, organoleptic, microbiological, mathematical and statistical, methods of system analysis, planning and processing of experimental data using modern computer programs.

During theoretical and experimental work, the technology of semi-finished products for frozen desserts in the form of a liquid mixture for soft ice cream based on whey, fructose and lactulose was considered as the main object of research.

The following main materials were used within the specified object: whey according to DSTU 7515:2014, dry milk according to DSTU 4273:2003, stabilization system for the production of ice cream CREMODAN SI 320, containing alginate, locust bean gum, guaran, carrageenan, according to certificate of the manufacturer ("Danisco A/S", Denmark); lactulose (crystalline lactulose "Lactulose" manufacturing company "ServaFeinbio Chemica", Germany) and fructose, which were purchased from "Altex" LLC, Dnipro.

The organizational aspects of the scientific work consisted in conducting a number of studies aimed at studying the characteristics of the initial components, the selection of rational ratios of recipe components, organoleptic, physico-chemical, structural-mechanical properties, technological indicators of products, their shelf life, establishing the possibility of practical use of the developed technology in production conditions.

Research of organoleptic, physico-chemical and microbiological characteristics of model systems, semi-finished products and culinary products was carried out by modern methods according to standard methods, using appropriate devices. The

selection of samples and their preparation for research was carried out according to standard methods.

The stability of the foam structure of the systems was determined after a 15-minute proofing of the whipped mixture according to the formula:

$$УП = \frac{B_n^{15}}{B_n} \times 100\%$$

where УП – foam stability, %;

B_n^{15} – foam height after proofing, m;

B_n – initial foam height, m.

Determination of the heat resistance of the mixtures was carried out according to the method developed by V. M. Polishchuk. The samples of the mixtures in glass chemical cups were mixed in a water bath, with the help of which it was possible to carry out different modes of heat treatment, in the range from 78 to 95°C and with different durations of exposure at a given temperature The heating of the mixtures was carried out with their continuous mixing, which prevented local overheating. Heat treatment was carried out at 4 temperature regimes – (80±2)°C, (85±2)°C, (90±2)°C, 95°C. For each regime, the mixture was processed until the moment of coagulation of milk proteins was established. The duration (in minutes) during which the mixture was kept at the specified temperature regime until the visible coagulation of the proteins in it began was chosen as a criterion for heat resistance of the mixtures.

The quality of mixtures and ready-made ice cream was determined by physico-chemical parameters (mass fraction of moisture – DSTU 5867, mass fraction of fat – DSTU 5867, mass fraction of sucrose – DSTU 3628). The selection of samples and their preparation for research were guided by the requirements of the current DSTU.

IV. RESULTS

4.1. Study of the influence of recipe components on the technological indicators of mixes for frozen desserts

The further aim of our work was to study the effect of different concentrations of stabilizer and fructose on the foaming ability and foam stability of the control and whey-based mixture. To do this, a certain amount of stabilizer and fructose was measured, introduced into the serum and the mixture was mixed until the stabilizer was completely dissolved. In a water bath, the system was brought to a temperature of 70...75°C and held for (10...15)·60s^{-1}. Cooled to room temperature. Model mixtures based on whey with a fructose content of 10-12% and a stabilizer content of 0.1...0.6% were subject to research. The study of the foaming ability and foam stability of the samples was carried out according to the methods described in section 2. The results of the studies are presented in fig. 1-3.

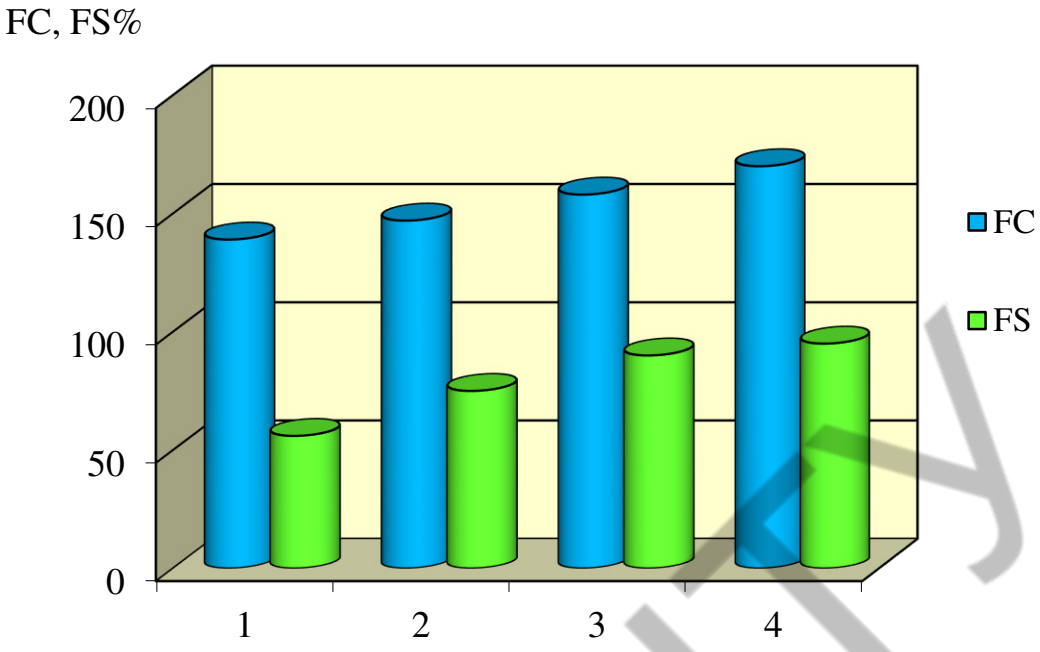

Fig.. 1. Foaming capacity (FC) and foam stability (FS) of control (1) and mixtures based on serum with a stabilizer content of 0.2; 0.4; 0.5 and 0.6% with a fructose content of 10%.

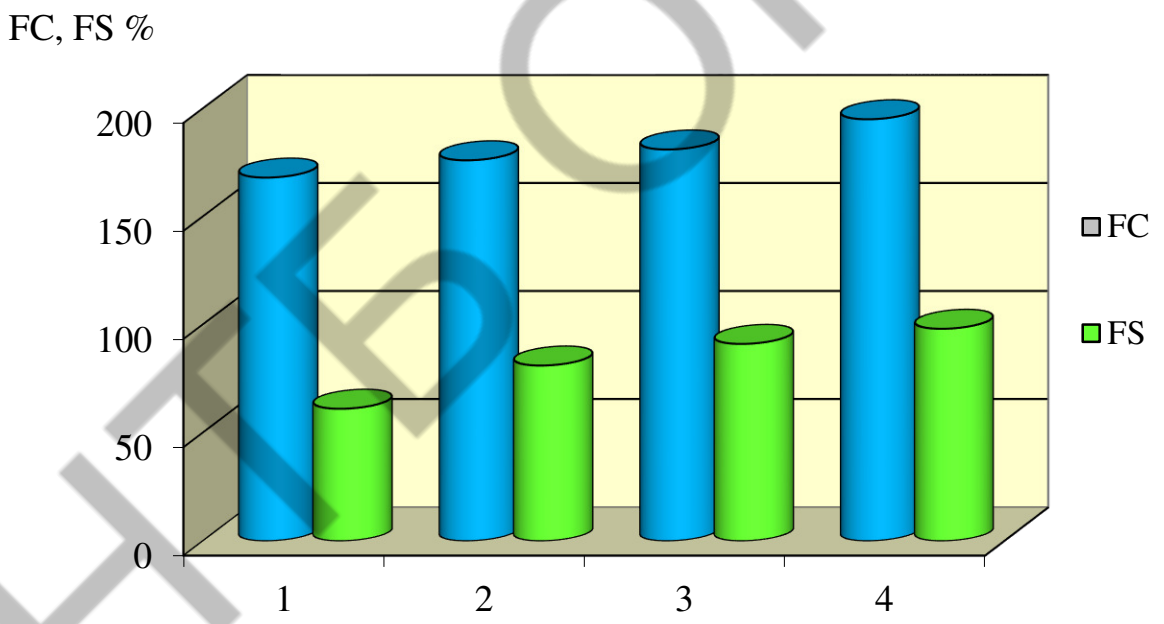

Fig. 2. Foaming capacity (FC) and foam stability (FS) of control (1) and mixtures based on serum with a stabilizer content of 0.2; 0.4; 0.5 and 0.6% with a fructose content of 11%.

The analysis of the obtained results allows us to draw the following conclusions. With an increase in the concentration of the stabilizer in the system, its foaming ability first increases to a maximum value, and then gradually decreases. This regularity is characteristic of all nonionic surface-active substances, which, in our opinion, can be explained as follows.

In the stabilizer concentration range of 0.4%, the foaming ability increases and

reaches maximum values. This interval corresponds to the critical concentration of micelle formation, at which the formation of an adsorption layer with maximum mechanical strength is completed, which prevents the coalescence of bubbles of the gaseous dispersion phase. The decrease in the critical concentration of micelle formation is explained by the presence of a synergistic effect during the interaction of the stabilizer we have chosen with milk protein, the amount of which increases with the increase in the concentration factor.

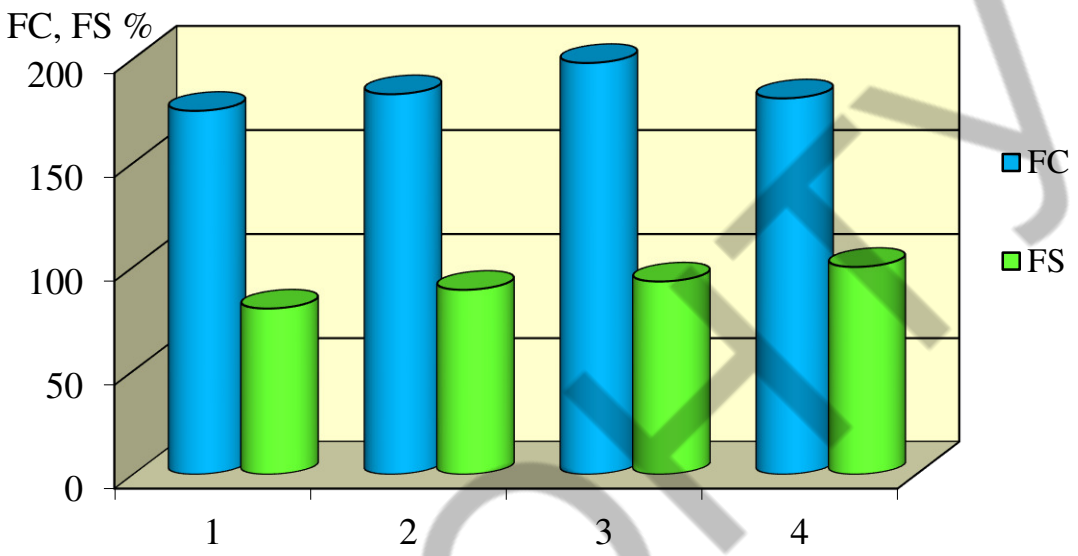

Fig. 3. Foaming capacity (FC) and foam stability (FS) of control (1) and mixtures based on serum with a stabilizer content of 0.2; 0.4; 0.5 and 0.6% with a fructose content of 12%.

A further increase in the concentration of the stabilizer (0.6%) above the critical concentration of micelle formation leads to the fact that the rate of diffusion of molecules to the surface layer decreases due to the increase in the micellar concentration of the components of the stabilization system. At the same time, the surface tension of the mixture practically does not change, and the foaming ability gradually decreases.

Thus, the most rational formulation of the mixture should be considered formulations based on serum with a fructose content of 11.0%, stabilizer 0.4.

4.2. Study of heat resistance of mixes for frozen desserts

Pasteurization is one of the most important operations in the production of mixes for soft ice cream and frozen desserts. The defining parameters of this treatment are the temperature and duration of its effect on the mixture, which determine its effectiveness.

The heat resistance of model mixtures is influenced by individual recipe components. Therefore, in order to develop the necessary modes of heat treatment of liquid semi-finished products for frozen desserts, a study of their heat resistance was conducted. Research on thermal stability was carried out in the temperature range of 80...95ºC.

Table 1. Heat resistance of model mixtures for sweet dishes

The name of the sample	Heat resistance of mixtures during heat treatment, $\cdot 60^{-1}$sec			
	80±2ºC	85±2ºC	90±2ºC	95±2ºC
Control [8]	12±0,3	6±0,2	4±0,3	2±0,2
A mixture based on whey with lactulose and fructose	6±0,2	4±0,2	3±0,15	0

The results of the conducted research confirm that the composition of mixtures for frozen desserts affects their heat resistance. It was established that the addition of recipe components significantly reduces heat resistance: at a processing temperature of 80...82ºC, the heat resistance of the mixture [8] decreases by 1.7 times, and that of the developed 1% mixture by 2 times. With a further increase in temperature, the heat resistance of the above-mentioned mixtures decreased. The decrease in the level of heat resistance of the latter can be explained by the fact that with an increase in dry substances in the mixtures, the content of mineral elements increases, which leads to a change in the ionic balance in the system and affects the stability of milk proteins, as well as due to an increase in the acidity of the mixtures. Thus, it is rational to carry out the pasteurization process for the semi-finished product – at a temperature of 80...82ºC for $(5.8...6.2)\cdot 60^{-1}$s.

Thus, on the basis of the set of researches, the most rational formulation of the mixture from the point of view of the properties of the obtained semi-finished product should be considered the formulation based on whey with the content of lactulose 1%, fructose 11.0%, stabilizer 0.4%, milk powder 8%. All the results obtained in this section were taken into account in subsequent studies, namely during the development of technological schemes of semi-finished products for frozen desserts.

4.3. Research of functional and technological properties of the semi-finished product

In order to determine the objective assessment of quality, the functional and technological properties of the developed semi-finished products were investigated: the ability to whip, the ability to form stable foams, the degree of dispersion of the fat phase. As a control, a mixture for soft ice cream was used [8]. The degree of dispersity of the fat phase was assessed by determining the average diameter of fat globules of control and developed semi-finished products. The obtained data are given in table. 2.

Table 2. Functional and technological indicators of the semi-finished product

Indicators	Control	Semi-finished product
Beating ability, %	60±1,5	70±1,8
The ability to form stable foams, %	65±1,5	80±2,0
The degree of dispersion of the fat phase, μm	110±2,8	90±2,3

The analysis of research results showed that the semi-finished product has a higher whipping capacity (by 9.8...10.2%) compared to the control sample. The developed semi-finished product is able to form more stable foams - 1.3 times more

than the control sample. The degree of dispersion of the fat phase of the semi-finished product is 1.2 times higher than that of the control sample. The obtained data were used during the development of the semi-finished product quality model.

4.4. Study of the nutritional value of the semi-finished product

Since the developed semi-finished products are new, non-traditional products planned for further use in the production of culinary products, it was necessary to investigate their nutritional value.

The concept of quality of food products is understood as a wide set of properties characterizing nutritional and biological value, organoleptic, structural-mechanical, functional-technological, sanitary-hygienic and other properties of the product, as well as the degree of their expressiveness. From the point of view of quality indicators, a food product must contain components necessary for the human body for normal metabolism.

The content of the main food substances in the developed semi-finished product, as well as its energy value are presented in the table. 3.

Table 3. Chemical composition of the semi-finished product

Product names	Content, g per 100 g					Energetic value, kcal
	Dry substances	Proteins	Lipids	Carbo-hydrates	Ash	
Control [8]	29,0±0,5	3,78±0,1	8,0±0,2	15,0±0,3	0,7	147,0
Semi-finished product	19,75	3,85±0,1	3,10±0,2	12,0±0,3	0,8	91,3

On the basis of the results, which are presented in Table 3.3, it is possible to produce biscuits, which the disintegration of the finished product is enriched with a high content of all nutrients, and it is possible to use vikoristany for processing in the product of eating without reducing the nutritional value. In addition, the disintegration of the finished product against lactulose in the amount of 1 ± 0.02 g / 100 g.

It is important to characterize the protein speeches of the napivfabrikativ, that the stench can be brought up to the high-bility, high-yield and sufficient balance for the amino acid warehouse of the produktiv. Advances in protein allow recommending the inclusion of dietary supplements on the basis of dispersed beverages in the consumption of protein diets.

In this manner, we carried out an investigation about the high biological value of the dispersed beverages.

4.5. Basic technological diagram of semi-finished product production

Based on a series of preliminary studies, a basic technological scheme for the production of semi-finished products for frozen desserts was developed (fig. 4).

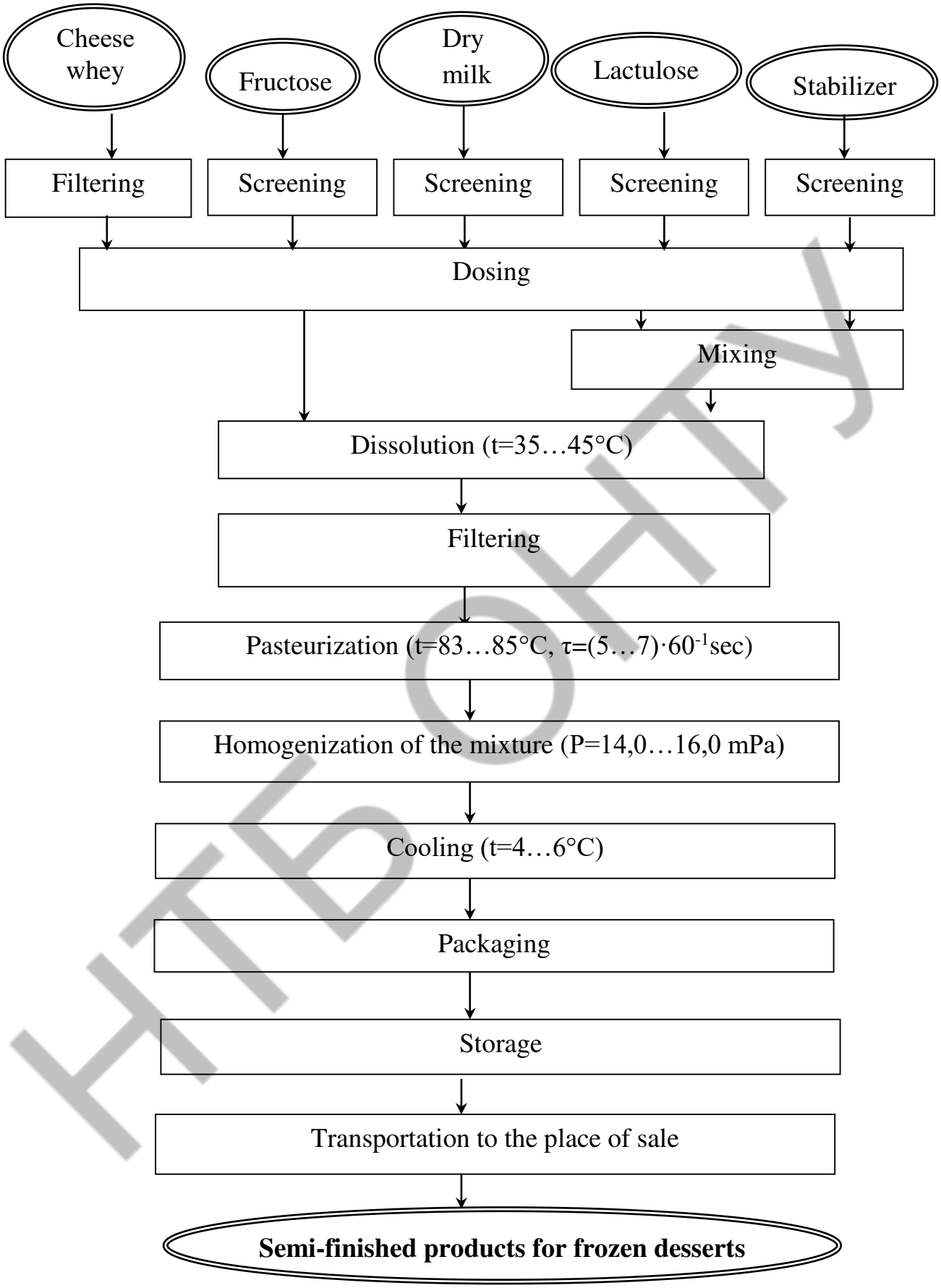

Fig. 4. Basic technological diagram of a semi-finished product for frozen desserts

4.6. The main areas of use of semi-finished products in the production of frozen desserts

The semi-finished product technology substantiated in the previous sections is low-waste, resource-saving and easy to implement. The production of the developed semi-finished product can be carried out both at the enterprises of the dairy industry and at the enterprises of the restaurant industry. However, since the main raw material of the developed semi-finished product is inexpensive whey, its transportation from dairy plants to restaurant enterprises can significantly increase the cost of the semi-finished product. In connection with this, it is advisable to produce the developed product at dairy plants, and then use it as a semi-finished product with a high degree of readiness at restaurant enterprises.

During the study of the process of freezing desserts from a semi-finished product, as well as those made according to traditional technology (a control sample), it was found that during the preparation of soft ice cream based on a semi-finished product, it is rational to carry out the freezing process for $(6...7)\cdot 60^{-1}$s. The obtained data were used during the development of a technological scheme for the preparation of soft ice cream and frozen desserts based on semi-finished products (Fig. 5).

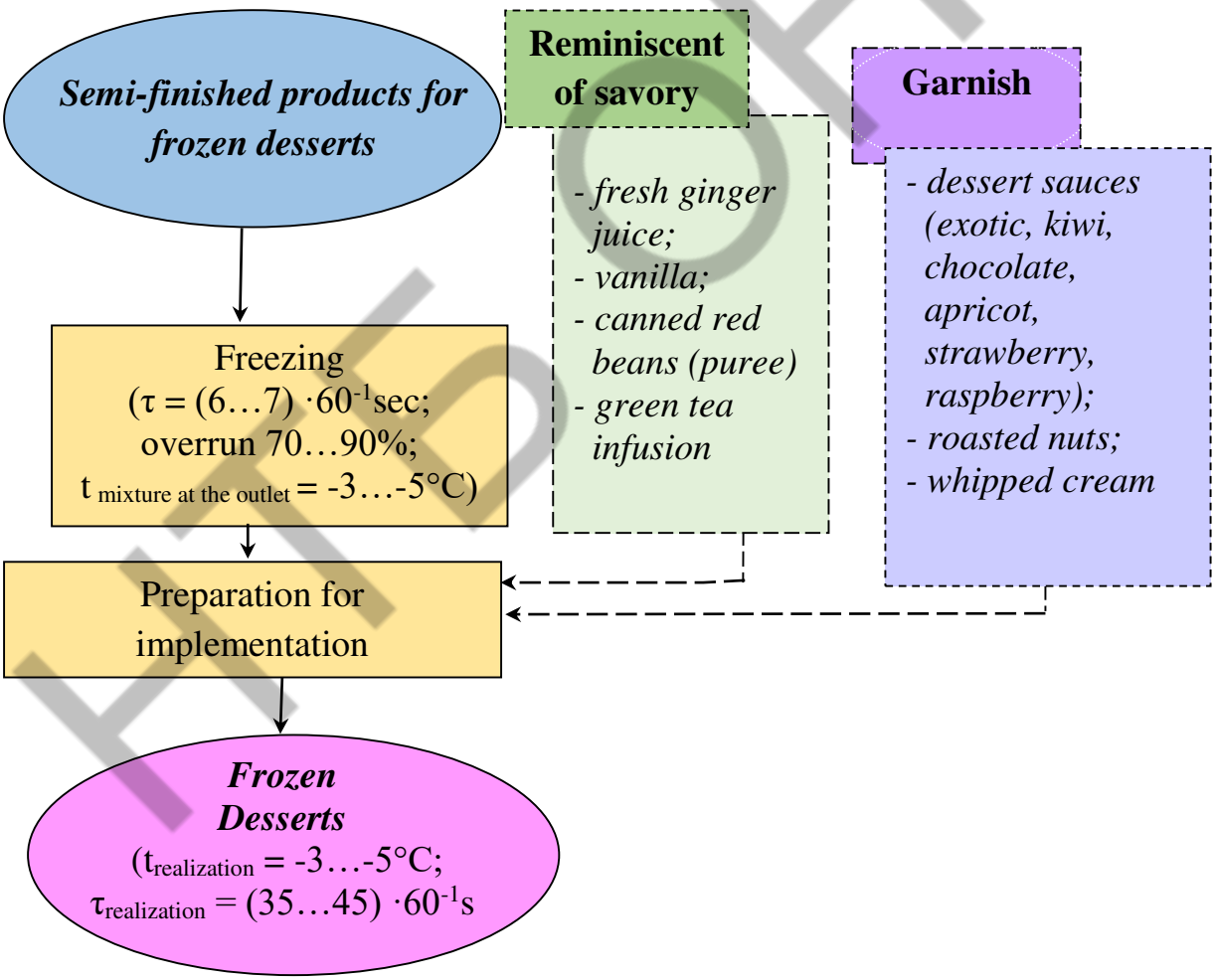

Fig. 5. Schematic diagram of the production of frozen desserts from semi-finished product

The semi-briquettes supplied to the restaurant industry must comply with the draft technical conditions in terms of quality requirements. Products are received in batches. Each batch must be accompanied by a document of the prescribed form certifying its quality and safety. The semi-finished product is delivered to the catering industry vacuum-packed in bags made of polyethylene or polymer materials with a capacity of 1...5 liters. The semi-finished product is stored at a temperature of 4...6°C for no more than 3 months, in unpacked form - no more than 48 hours. Before use, the bags are opened, then the semi-finished product is used in accordance with the recommendations for preparing dessert dishes.

We developed original technologies of frozen (soft) ice cream "Ginger", "Fasoleve", "Green tea" and original desserts.

Prospects for further research in this direction are the determination of the nutritional value of the developed frozen desserts and their functional properties (physiological action) and their glycemic index.

Thus, the basic technological scheme of the semi-finished product was developed and substantiated, the rational ratio of components in the semi-finished product based on milk whey was determined (lactulose 1%, fructose 11.0%, stabilizer 0.4%); its consumer characteristics and main directions of use in the production of culinary products are determined; recipes and technologies of ice cream and frozen desserts based on semi-finished products have been developed.

V. CONCLUSIONS

The analysis of literary sources showed that the creation of products with reduced glycemic load and functional properties are new ways of improving the technologies of ice cream and frozen desserts.

It has been proven that lowering the glycemic index is possible by replacing sugar with fructose or other sugar substitutes.

Provision of functional (prebiotic) properties is expedient to be carried out at the expense of the introduction of lactulose.

It has been proven that the rational formulation of the mixture from the point of view of the properties of the obtained semi-finished product should be considered formulations based on serum with the content of lactulose 1%, fructose 11%, stabilizer 0.4%, dry milk 8%.

The optimal pasteurization process for the semi-finished product was determined - at a temperature of 80...82°C for $(5.8...6.2)\times60^{-1}$s.

The whipping ability was 70±1.8%, the ability to form stable foams was 80±2.0%.

A technological scheme for obtaining a semi-finished product for frozen desserts based on whey with lactulose, fructose, stabilizer was developed.

A set of data characterizing the quality of the developed semi-finished product was obtained, and its high nutritional and biological value was proven.

Modes and terms of storage of semi-finished products are substantiated: temperature -4...6°C, no more than 3 months, in unsealed form – no more than 48 hours.

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DEVELOPMENT OF THE TECHNOLOGY OF SAUSAGE PRODUCTS FROM AFRICAN CATFISH

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Abstract. *The work substantiates the feasibility of developing the technology of fish sausages from African catfish. On the basis of the analysis of literary sources, the priority directions of processing fish raw materials and expanding the range of fish products are determined. An analysis of the existing technologies of fish sausage products was carried out. The prospects for the production of fish sausages have been established. The expediency of using African clary catfish (Clarias gariepinus Burchell, 1822) as a raw material for the production of sausage products has been theoretically substantiated and experimentally confirmed. The effectiveness of combining catfish meat with other hydrobionts and animal raw materials is shown. New recipes of raw-smoked sausages based on African catfish with the addition of mackerel, sea scallop and lard have been developed. A study of organoleptic, physico-chemical indicators of quality and nutritional value of finished products was conducted. According to the results of the research, the compliance of the indicators with the requirements of the standard was established. The results of the chemical composition study indicate the high nutritional value of the developed sausage products. On the basis of theoretical and experimental studies, a technological scheme for the production of raw-smoked sausages from African catfish was developed.*

Keywords: *African catfish, fish sausage, recipe, technological scheme, nutritional value.*

I. INTRODUCTION

Today, fish and its processed products occupy an increasing share in the human diet, primarily due to the high nutritional benefits associated with the chemical composition. The range of products produced by fish processing enterprises of Ukraine is almost constant, which does not ensure the growth of demand and high demands of consumers.

Technologies for sausage products made from hydrobionts are being successfully developed and implemented in many countries of the world, but the production of these products is limited in Ukraine. Therefore, developments aimed at the use of new types of raw materials, improvement of the technological process of production and recipe composition are gaining special relevance.

The classification of sausage products opens up the possibility of production of a wide range of products - sausages, sausages, sausages, combining the recipe components of which (inclusion of additional raw materials) solves the problem of expanding the range of sausage products.

Recently, African catfish (*Clarias gariepinus*), as a promising object of cultivation and processing, has received a lot of attention. It has valuable meat, is characterized by high growth rates, uses low-cost feed for feeding, and is unpretentious

to the conditions of keeping [1, 2].

The meat of clary catfish has high nutritional and culinary properties. Due to the optimal combination of proteins, fat and amino acids, fish is ideal for children's and dietary food, and the absence of small bones makes it convenient for cooking and eating. The high content of Omega-3 polyunsaturated fatty acids helps to reduce the level of cholesterol in the blood, prevents blood clots, and also has a beneficial effect on strengthening the vessels of the brain. The product is hypoallergenic. Even people with pronounced allergies to fish and seafood can eat meat. African catfish tastes more like animal meat than fish [3].

The development of sausage products from African catfish for further introduction into production at domestic enterprises is relevant.

II. LITERATURE ANALYSIS

Modern principles of creating high-quality sausage products are based on the selection and justification of certain types of raw materials in such ratios that would ensure the achievement of the predicted product quality, high organoleptic indicators and certain technological food characteristics.

The technology of making sausage products includes preliminary processing of raw materials and materials, assembly of sausage mixtures, injection of mixtures, heat treatment and storage of products. The quality of food products is assessed mainly by organoleptic indicators. The properties of sausage products, even of one type, vary widely, which is caused by the difference in the chemical composition of the raw material and the different degree of its processing.

Fish raw materials are used in the recipe of meat-rich sausage cooked from waterfowl meat, which includes ingredients in the following ratio: ground duck meat (muscovy duck) - 30-40%, minced fish (silver crucian carp) - 40-50%, lard - 10%, dry whey - 5%, wheat flour - 1%, eggs or melange - 4% and spices. Samples were made according to the technology of cooking minced meat for cooked sausages [4].

According to the patent (CN №104116091A), the technology of obtaining fish sausage by air drying is known. It involves thawing the fish, cutting the raw material into small pieces of 1-1.5 cm, marinating at a temperature of 0-5 degrees for 2-4 hours, fermentation for 1-3 hours at a temperature of 25-35 degrees, drying for 5-8 hours at a temperature of 10-20 degrees by drying, weighing, packing, vacuum sealing; sterilization at 115-121 degrees for 10-25 minutes, air drying, packaging. Fish sausage made in this way has a good taste and consistency, can be stored at room temperature and is ready for consumption.

In Japan, a sausage made of fish raw materials and spices has been developed, which is stuffed into a thin casing and eaten fried or boiled (JP №2008182897A). The sausage is prepared exclusively from fish and spices, it can be consumed within five days after production and has good organoleptic properties.

According to the method of making sausage from fish meat (KR № 102286395B1), not only a wonderful texture is provided without the use of pork or pork fat, but also the shelf life is increased. A mixture of pollock and sea bream in the ratio of 6:4 is mainly used as raw material. The method of production of sausage from fish meat includes the stages of grinding fish meat, emulsification, mixing minced meat with all ingredients,

injection of casings and heat treatment. Potato starch, which is most often used as a thickener in the technology of making sausages, is the reason for the deterioration of the existing quality of fish sausages. Therefore, potato starch, modified potato starch and tapioca starch are used as a stabilizer in this recipe in a ratio of 7:2:1. Carrageenan is also added to the minced meat mixture as a thickener. The following seasonings are used in the recipe: table salt, granulated sugar, soy sauce, a mixture of peppers, cheese and beetroot powder. The developed technology solves the problem of short shelf life caused by the use of natural starch in existing fish sausages. It is a technology with a very high industrial impact, as it can contribute to increased sales and increased profits.

A cheese fish sausage with a high calcium content and a method of its preparation have been developed in China (CN №107095204A). Fish bones are turned into ultra-thin fish bone paste and added to fish sausage. This technology reduces the cost of sausage products. Fish sausage with a high calcium content is rich in nutrients and is especially suitable for consumption by children and the elderly.

The technology was developed and textural and sensory properties of fish sausage made from chilled and frozen rainbow trout (Onchorynchus mykiss) and stored for 14 days at 0–4 °C were determined [5].

A variety of fish sausage is sausage with fruit and vegetable compound (CN № 106333278A). When properly dissolved and joined, the resulting composite fish sausage has a more elastic texture, moderate hardness, and uniform texture than fish sausage made by prior techniques. Fruits and vegetables are added in the form of granules. After adding to fish sausage, the granules can retain the original taste and color of fruits and vegetables, and its elasticity is similar to that of fish sausage. Pectin, sodium alginate, agar, carrageenan can be used as a coagulant.

Developed fish sausage containing fish meat, surimi, potato starch, soy protein, modified tapioca starch, soy fiber, salt, sugar, garlic powder, vegetable oil, chicken eggs (TH №11885C3). The technology was developed and the physico-chemical and sensory properties of sausages made from washed and unwashed Nile tilapia by-products were evaluated [6].

The technology was developed and the physico-chemical and sensory properties of sausages made from washed and unwashed Nile tilapia by-products were evaluated.

In Brazil development and evaluation of fresh sausage type of marine catfish stored under low temperatures. The sausages of marine catfish featured good nutritional quality, sensory, and shelf life between 21 to 25 days when kept under refrigeration and four months under freezing [7].

Three types of fresh fish sausage were prepared, one from Clarias lazera, the other from Tetradon fahaka while the third from a mixture of the two species. Nutritional composition, sensory evaluation and microbiological detection of fish sausage made from mince of the two species and a mix were determined [8].

According to patent US20120294982A1, the use of clary catfish in the production of fitness cooked sausage and sausage made of fish, soybean and pork is known. The object of the invention is to provide a meat-mix based foodstuff that altogether omits the admixing of usual empty fats, which is compensated by the addition of lean fish meat having a high content of natural marine omega-3 fatty acids present in fish meat, from particular fish species and, if needed, the admixture of essential vegetable and marine

omega-3 fatty acids in the form of triglycerides and/or ethyl esters thereof as well as plant protein isolates, water-soluble and/or oil-based antioxidants, in order that four objects are achieved: optimum taste; avoiding lifestyle diseases even; continuous metabolization; significant improvement of the taste properties during the storage period, especially of sliced sausages.

Fish sausages are made in Germany (DE №102007025847A1) based on the meat of clary catfish (*Clarias gariepinus*) and freshwater catfish (*Heterobranchus longifillis*). Fish meat with a fat content of less than 7% is used to prepare minced meat. According to the recipe, salt and/or nitrite for marinating and spices are added to the minced fish. The technology of this sausage differs in that carbohydrate-based hydrocolloids are added to the meat base during the cutting process.

The well-known technology and recipe of Chinese-style fish sausage, made from the clarias catfish hybrid. The variations studied were kinds of lipids, i.e., pork fat or palm oil; amount of palm oil between 5 and 10 % (w/w) of fish meat; amount of spices between 1.2 and 1.6 % white pepper or 1.2 % white pepper plus 1.5 % mixed 5 spices powder (cinnamon, cardamom, coriander, star anise, fennel); drying time at 50◦C for 28 or 48 hours [9].

In Turkey production of a dry sausage from African catfish and determination of its microbial, chemical and sensory properties during a 70-day storage at both 4 and 22◦C were prompted [10].

The successful foreign experience of manufacturing various fish sausage products, including those based on clary catfish, testifies to the expediency of this direction of the domestic fish processing industry.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The object of research is the technology of sausage products based on the meat of the African clary catfish.

The subject of the study is quality indicators of fish raw materials; sausages made from African catfish meat; indicators of quality and safety of fish sausages during storage.

Studies of the chemical composition have been performed according to the following methods: mass fraction of moisture – by drying the product sample to a constant weight in an oven SNOL (Labimpex LTD, Ukraine) at a temperature of 100-105ºC according to DSTU 8029:2015; mass fraction of ash – by a weightning method, after the mineralization of a portion of the product in a muffle furnace SNOL (Labimpex LTD, Ukraine) at a temperature of 500−600°C according to DSTU 8718:2017; mass fraction of lipids – by the Soxhlet extraction-weight method according to DSTU 8718:2017 on the SOX 406 Fat Analyzer (Hanon Instruments, China); mass fraction of protein – by Kjeldahl method of the determination of a total nitrogen, which is based on the ability of organic matter of the product sample to be oxidized with concentrated sulfuric acid in the presence of a catalyst according to DSTU 8030:2015, while samples ashing has been performed on a DK6 digester (Velp Scientifica, Italy), with a vacuum pump JP, distillation has been carried out on a steam distillation apparatus UDK 129 (Velp Scientifica, Italy).

Determination of organoleptic parameters has been carried out by the profile

method using a 5-point scale, according to the recommendations of T.M. Safronova.

The acid number of lipids was determined according to DSTU EN ISO 660:2019. Peroxide number of lipids, according to DSTU EN ISO 3960:2019. The total volatile basic nitrogen according to GOST 7636– 85.

The number of mesophilic aerobic and facultative anaerobic microorganisms was determined in accordance with DSTU 8446: 2015; bacteria of the Escherichia coli group, according to DSTU GOST 30726: 2002; Staphylococcus aureus, according to GOST 10444.2-94; pathogenic microorganisms, including genus Salmonella, according to DSTU ISO 11290-1, DSTU ISO 11290-2.

Shelf life was determined by the dynamics of changes in the complex of organoleptic, physicochemical and microbiological indicators.

IV. RESULTS

At the first stage of research, the size and mass composition of the African catfish was determined (fig. 1).

Fig. 1. Determination of size composition of African catfish

Dimensional characteristics are given in tabl. 1.

According to GOST 1368-2003, a catfish is a large fish with a length of 53 cm or more, a small fish is a fish with a length of less than 53 cm, therefore, the studied samples of African catfish are small fish.

Table 1. Size composition of African catfish

Indicators	**L, sm**
Length:	
- absolute	50,1± 0,5
- industrial	44,3± 0,3
- head	10,3± 0,1
- tail fin	6,2± 0,2
- carcass	33,2± 0,3
Body height	7,9± 0,2
Body thickness	7,3± 0,2

The mass composition of fish depends on its sex, physiological state, season and other factors. The dependence of the mass composition on the sex of the fish is due to the different sizes and mass of mature sexual products in males and females, and seasonal differences are associated with changes in the size of sexual products during

their development and spawning, as well as with uneven nutrition and different fatness of fish. As the fish ages, the mass of edible parts increases due to the development of fat and muscle tissue. The results of the study of the mass composition of clary catfish are presented in tabl. 2.

Table 2. Mass composition of African catfish

Fish body parts	**The mass fraction**	
	grams	**%**
Whole fish	758± 0,2	100
Fish without fins	747±0,3	98,5
Fish without bowels	731±0,9	96,4
Headless fish with shoulder bones	524± 0,3	69,1
Fillet with skin	440± 1,4	58,0
Fillet without skin	390± 0,5	51,4
Head	207± 0,3	27,3
Bowels	16± 0,9	2,1
Fins	11±0,3	1,4
Bones	84± 0,6	11,1
Skin	50± 0,5	6,5
Output	390± 0,5	51,4
Waste	368± 0,5	48,6

Analysis of the data in table 2 showed that the yield of clean fillet is 51.4%. The internal organs of catfish occupy a small volume - 2.1% of the weight of the fish. The practical absence of intercostal bones, a large content of muscle tissue makes the clary catfish a valuable object for processing.

The consumer properties of clary catfish meat are largely determined by its chemical composition. The results of the study of the content of moisture, protein, fat and ash are shown in fig. 2.

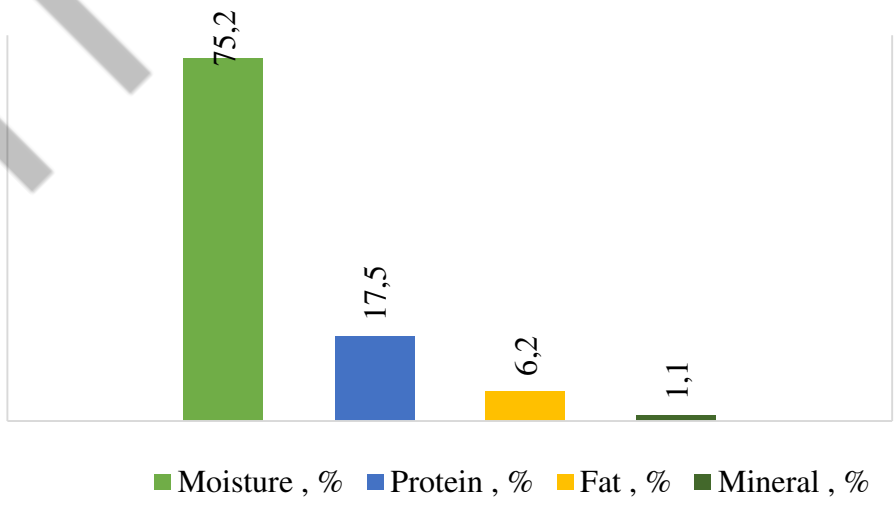

Fig. 2. Chemical composition of African catfish meat

According to the results of the chemical composition study, African catfish is a protein, medium-fatty fish. The research results are consistent with literature data [10].

One of the indicators of the quality of muscle tissue is the water-holding capacity. The study of the water-holding capacity of fresh (sample 2), chilled (sample 3) and frozen (sample 1) meat is presented in fig. 3.

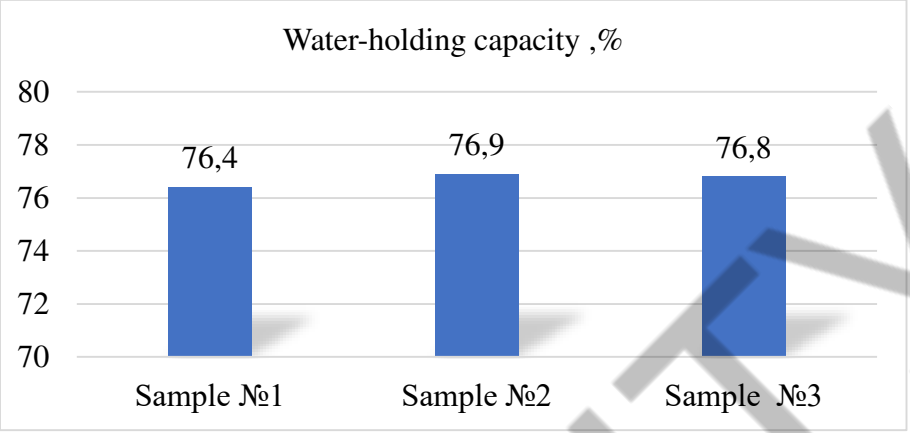

Fig. 3. Water-holding capacity of minced African catfish

The analysis of the data in Figure 3 shows the high water-holding capacity of the minced meat, so products made of African catfish will perfectly retain their shape, be juicy and tender.

Samples of sausages based on African catfish were developed with the addition of such ingredients as: Atlantic mackerel, sea scallop, pork lard and spices, which improve the organoleptic indicators of finished sausage products, increase their nutritional and biological value. Comparative characteristics of control and experimental samples of sausage products are presented in tabl. 3.

Table 3. Comparative characteristics of the recipe composition of control and experimental samples of African catfish sausages.

The name of the raw material	**Consumption of raw materials per 100 g**			
	Control	**Experimental samples**		
		№1	**№2**	**№3**
Pollack (pieces)	30	-	-	-
Pollack (minced)	30	-	-	-
African catfish (pieces)		30	40	30
African catfish (minced)		45	50	30
Atlantic mackerel (minced)	10	15	-	10
Sea scallop muscle	20	-	10	20
Pork lard is unsalted	10	10	-	10
Salt	2,0	2,0	1,2	1,5
Ground black pepper	0,1	0,1	0,1	0,1
Whole coriander	0,1	0,1	0,1	0,1
Ground nutmeg	0,1	0,1	0,1	0,1
Dried ground red hot pepper	0,05	0,05	-	0,05
Dried minced garlic	-	0,2	-	0,2
Ground paprika	-	-	0,1	0,2
Cumin seeds	-	0,05	0,1	0,05
Dried ground ginger	-	0,1	-	0,1

The technical result of the developed recipe consists in obtaining high-quality raw-smoked fish sausage from African catfish, which has a high nutritional value due to the combination of pre-salted fish raw materials and raw non-fish raw materials. At the same time, the quantitative ratio of the selected components makes it possible to obtain a high-quality finished product.

For the production of fish sausages, fresh and frozen fish raw materials of a quality not lower than the first grade were used. After thawing, the fish was washed in running water, the temperature of which does not exceed 15 °C, to remove mucus and other impurities from the surface of the fish, and it was cut into fillets. Lard was chopped into 5×5 mm pieces. The fish fillet was salted and kept at a temperature from 0°C to 10°C for 6-12 hours until the salt content was 3%.

Part of the fish raw material was ground into pieces, and the other part of the fish raw material was added to the minced meat mixture in the form of pieces with geometric dimensions equal to 1.0-2.0×10-2 m, in order to obtain the fibrous structure of the finished sausage products. Food and flavor additives were added to the minced meat mixture.

Prepared natural casings (pork bellies) were filled with ready minced meat and loaves were formed. The obtained loaves were kept in a ripening chamber at a temperature from 0°C to 10°C and a relative humidity of no more than 75% for 12...36 hours until the average value of the buffering index is at least 70°.

Smoking was carried out by the convective method at an air temperature of 45-60°C until a homogeneous state and reaching an average water content of no more than 55%. After smoking, the obtained sausage products were dried by the convective method at an air temperature of 19°C to 25°C and a relative air humidity of 75...85% to an average value of the mass fraction of water no more than 50%.

A developed sample of African catfish sausage is presented in Fig. 4.

Fig. 4. Fish sausage from African catfish

In order to substantiate the expediency of combining clary catfish meat with Atlantic mackerel meat, sea scallop meat and raw materials of plant origin, an organoleptic evaluation of the compatibility of these ingredients in fish sausages was carried out using the flavor profile method.

To characterize the taste of African catfish sausages, a profile analysis has been performed by the method of flavor based on selected descriptors. In order to better visualize the results for each of the samples, detailed organoleptic profiles of the flavor have been developed, and a comparison with the "ideal" profile have been performed (fig. 5).

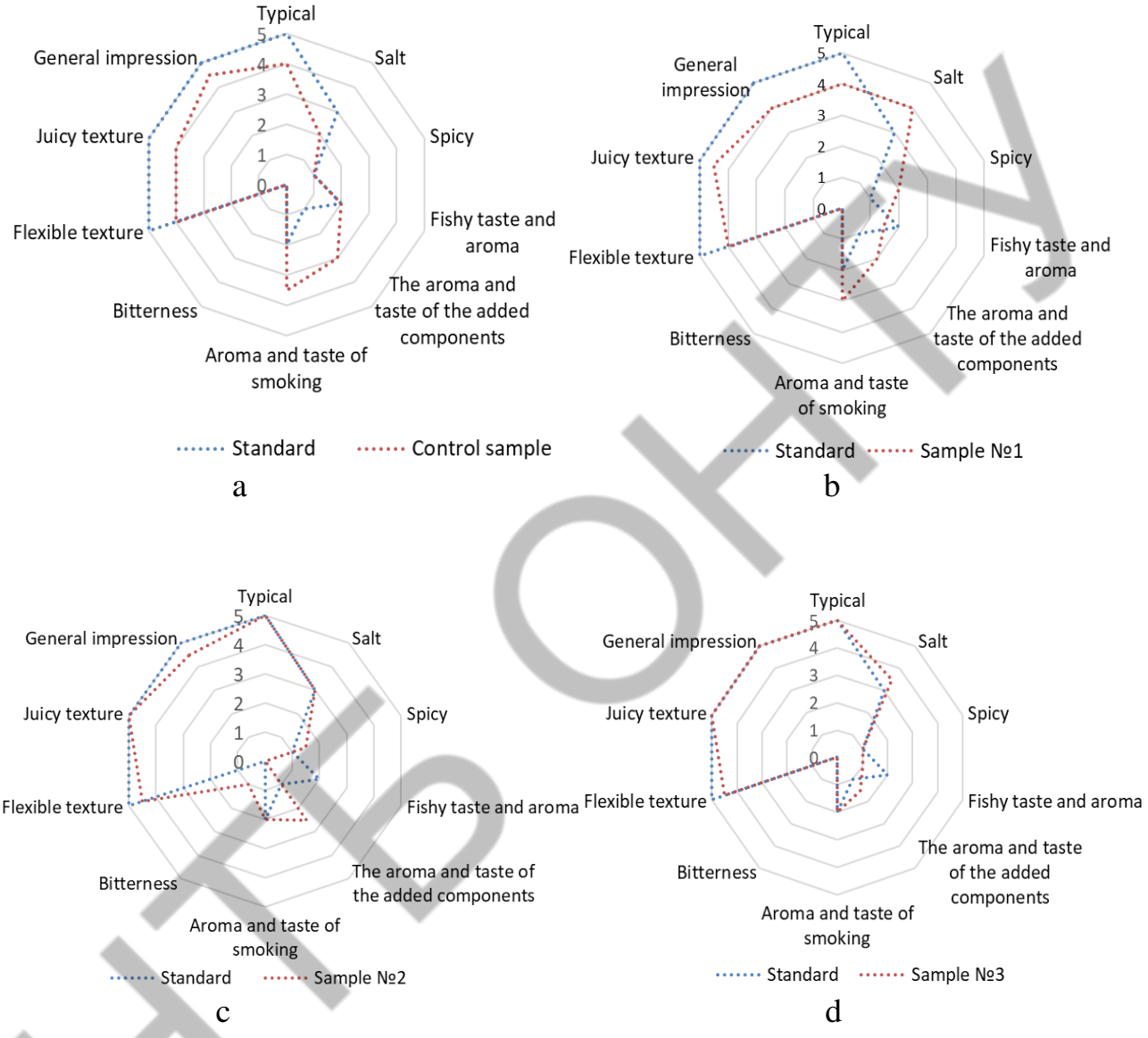

Fig. 5. Fish sausage flavor profiles: a – control sample, b – sample №1, c – sample №2, d – sample №3

According to organoleptic profiles, the most similar to the "ideal" is the profile of fish sausage made according to recipe № 3.

As a result of the assessment of the compatibility of the ingredients in fish sausages using the flavor profile method, it was established that the addition of minced fatty fish, namely mackerel, and pieces of lard and sea scallop to mincemeat made from lean fish increases the taste properties, appearance and creates an elastic consistency and a whole sausage structure. Flavor and aroma indicators are improved by spices and seasonings, which were added by us according to the recipes. The addition of cumin,

paprika, ginger and garlic gives piquancy and original taste to the sausages.

The organoleptic evaluation of fish sausage products was carried out according to the following indicators: appearance, color, taste, smell, consistency. A comparison of the received samples of fish sausages with each other using the "Quality Polygon" is shown in fig. 6.

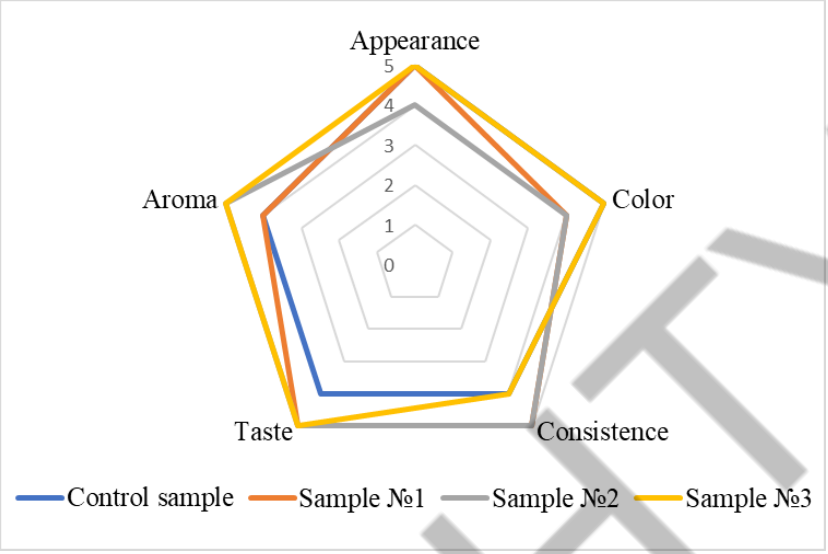

Fig. 6. Organoleptic evaluation of samples of fish sausages using the "Quality Polygon"

According to the organoleptic evaluation, sample № 3 is the best.

The main indicator of nutritional value is the chemical composition. The results of studies of the general chemical composition of formulations are given in tabl. 4.

Table 4. General chemical composition of recipes

Name of samples	**Chemical composition, %**			
	moisture	**fat**	**protein**	**ash**
Control sample	49,92±0,7	21,41±0,3	23,72±0,2	4,95±0,1
Sample №1	49,83±0,6	21,33±0,2	24,11±0,2	4,73±0,1
Sample №2	49,95±0,4	18,93±0,5	26,19±0,1	4,93±0,2
Sample №3	49,84±0,5	20,04±0,2	25,24±0,1	4,88±0,1

The results of the study of the chemical composition of the developed samples indicate a high nutritional value. The moisture content does not exceed 50%, which corresponds to the norm for raw smoked sausages.

The stability of fish products during storage is determined by the level of initial microbiological insemination, the qualitative composition of microflora, the type of raw materials, the pH level, the moisture content, the condition of the surface of the product, the temperature, the humidity of the environment and the speed of air circulation, non-compliance with the temperature conditions of storage, the type of packaging, the presence of bactericidal and bacteriostatic means, shells.

The results of studies of the organoleptic indicators of the manufactured sausage samples during storage at a temperature of 5-6 °C for 15 days are shown in fig. 7.

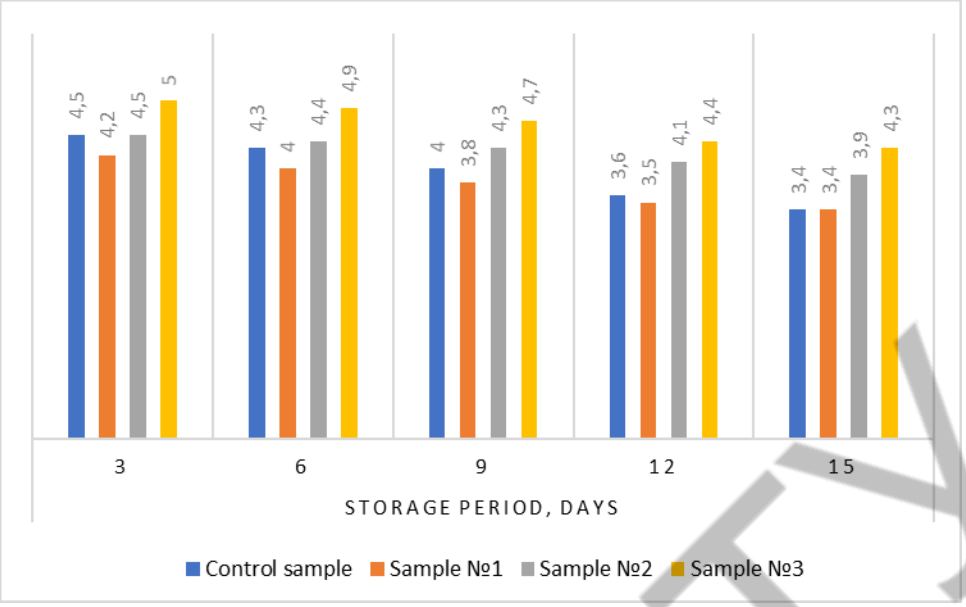

Fig. 7. Organoleptic evaluation of fish sausages during storage

It can be seen from Figure 6 that gradually during storage sausage products reduce their organoleptic indicators.

The developed samples of sausages have a high content of fish and animal fats in their composition. An important indicator is the assessment of the quality of the lipid component of products during storage. The course of hydrolysis and oxidation of fats in fish sausages was evaluated by acid and peroxide numbers.

The acid number of fat characterizes the presence of primary products of fat hydrolysis. The dynamics of accumulation of free fatty acids is shown in fig. 8.

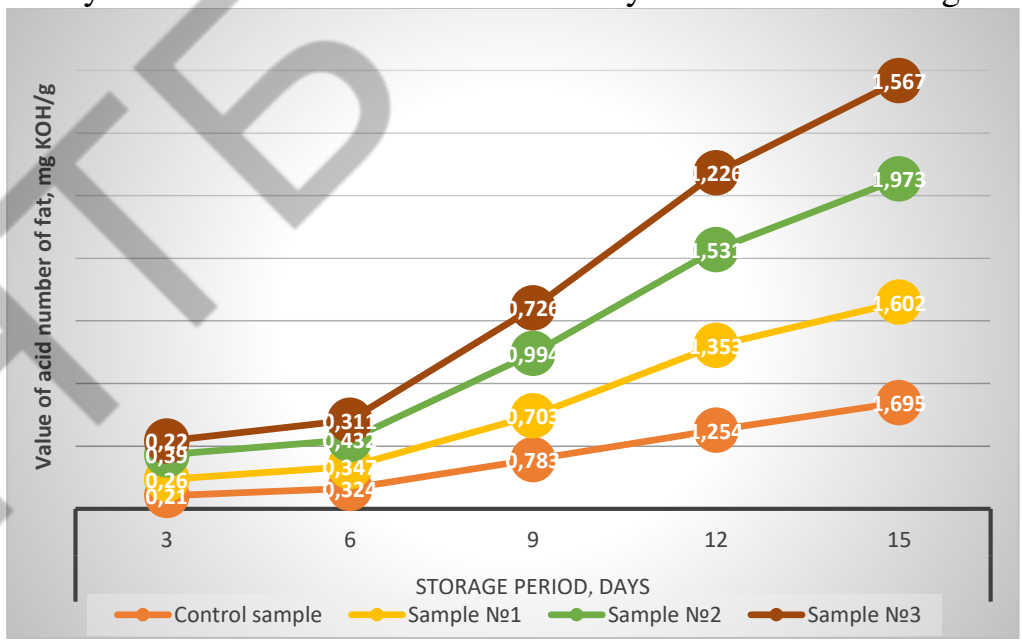

Fig. 8. Dynamics of acid number indicators in sausages

An increase in the acid value of fat during storage of fish sausages occurs due to the hydrolysis of triglycerides. During the entire storage period, the acid number of lipids in both samples does not exceed the norm established for fish fats for the

production of food products (4.0 mg KOH/1 g of fat).

The course of lipid oxidation processes in the initial stages is characterized by the peroxide number. The dynamics of the accumulation of peroxides and hydroperoxides during the storage of sausages is shown in fig. 9.

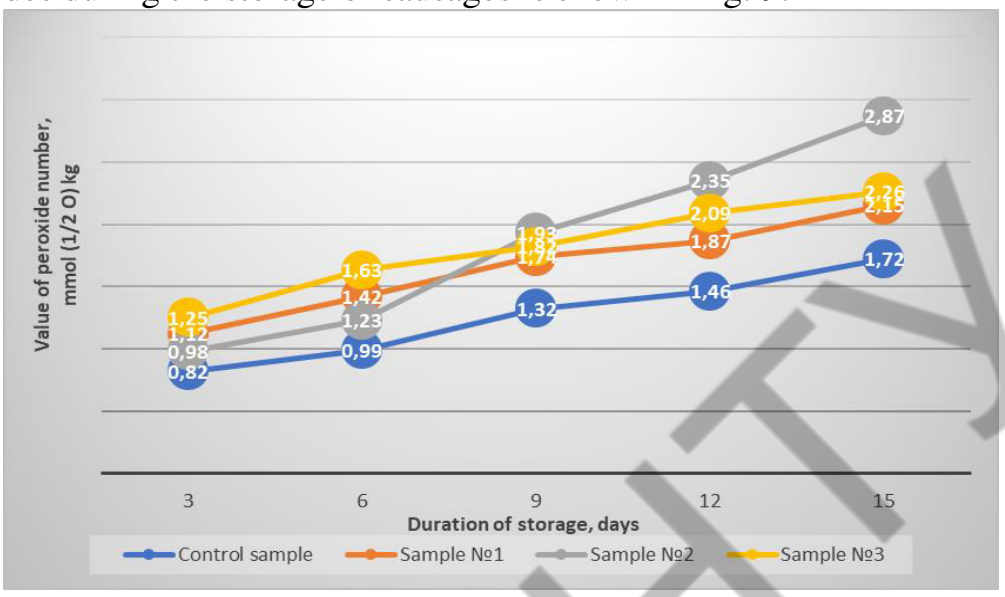

Fig. 9. Dynamics of peroxide number values in sausages

From fig. 8 it can be seen that the processes of fat oxidation occur more intensively in sample № 2, which is explained by the presence of hydrobionts in the lipid composition. On the 15th day of storage, the indicators of the fat peroxide number of all samples are significantly below the established norm of 10 mmol (1/2 O)/kg of fat.

The degree of microbiological processes and proteolysis was studied by changes in the total nitrogen content of volatile bases (fig. 10).

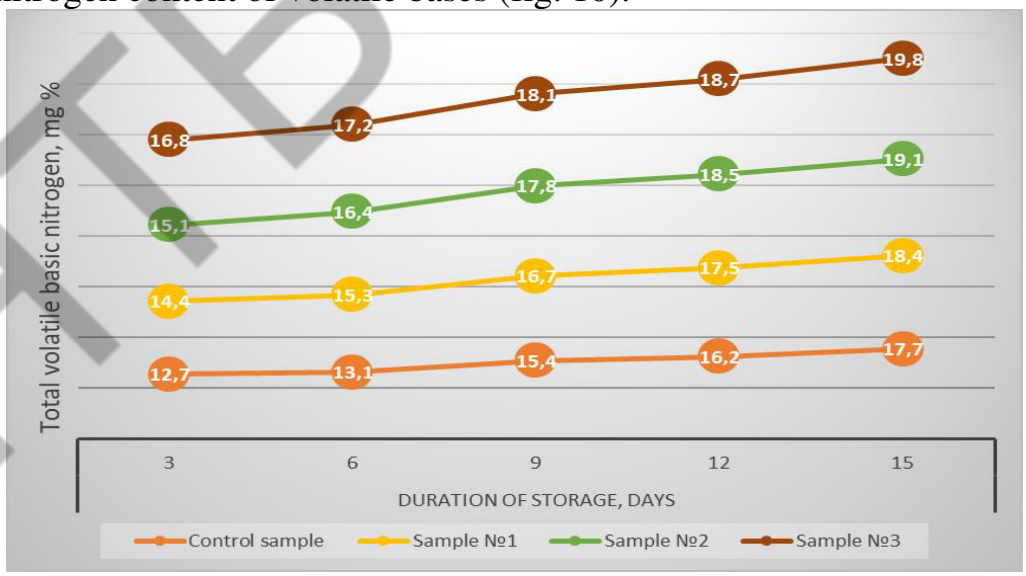

Fig. 10. Changes in indicators of total nitrogen of volatile bases in the process of storing sausages

In fig. 9, we can see that at the maximum product storage period of 15 days, the total nitrogen content of volatile bases does not exceed the permissible level of 30 mg%.

The safety of fish sausages was studied by microbiological quality indicators. On the 15th day of sausage storage, the number of mesophilic aerobic and facultatively anaerobic microorganisms is acceptable for product suitability, but close to the limit $5 \cdot 10^3$ CFU/g. Bacteria of the Escherichia coli group, Staphylococcus aureus, and Proteus were not detected in 0.1 g of the studied samples. Pathogenic microorganisms, including Salmonella and L. monocytogenes, were absent in 25 g of all sausage samples.

V. CONCLUSIONS

Based on the analysis of theoretical and experimental studies, the technology for the production of sausage products from African catfish was developed.

Based on the techno-chemical characteristics of African catfish, the expediency of using this raw material in the technology of sausage products has been confirmed.

Recipes of raw-smoked African catfish sausages with the addition of such components as mackerel, sea scallop, lard have been developed.

Organoleptic, physico-chemical, chemical, microbiological, studies of quality indicators of finished products were conducted. Based on the research results, the compliance of the indicators with the requirements of the standard was established.

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INTEGRATION OF TECHNOLOGY IN THE MECHATRON MODULE OF LIQUID DOSING

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Abstract. *The influence of individual parameters on the accuracy of product dose formation was determined during physical and mathematical modeling. We have found ways to ensure the necessary distribution of compressed air pressure, subject to compliance with the specified performance of the dispenser. Research results make it possible to improve the operation of dosing systems for liquid products with high dosing accuracy. The control system is formed on the basis of electro-pneumatic complexes. The control model with dosing operating modes is substantiated. It was established that the consumption of compressed air will depend on the value of the input main pressure P (0.05... 0.4 MPa).*

The consumption of the product was in the range of 1 ml to 50 ml with a feeder volume of 2.25 l. A mathematical model of the dosing process of liquid products (non-carbonated drinking water, milk, juice) has been developed. Boundary conditions took into account the influence on the formation of the product dose from the programmed current values in mA (with an accuracy of 0.001 mA) in relation to the standard scale Imin, Imax=4..20 mA.

An analytical description of individual stages of the dosing process with further analysis of individual stages and accepted assumptions was formed. Tests of the experimental sample of the dispenser showed the accuracy of the repetitions of the dose extrusion (limits ± 0.035% and 0.8%) from the set value of the dose mass up to 50 ml during the change and the initial liquid level in the reservoir of the dispenser feeder.

Keywords: *dosing, air lift system, excess pressure, feedback, dosing accuracy.*

I. INTRODUCTION

A number of small and medium-sized enterprises are now engaged in the production and packaging of liquid products in containers. In this regard, the problem of creating inexpensive and compact import-substitutable dosing and packaging equipment, taking into account the specific working conditions for small productions, becomes extremely urgent [10-27].

The systems of dosing and packaging modules for liquid products in containers, in the conditions of small productions, have specific requirements: high operational reliability, a wide range and high accuracy of dosing in combination with the possibility of rapid reconfiguration of the equipment for different types of liquids and dosing ranges; the possibility of smooth adjustment of the dose in a wide range; the possibility of prompt flushing or replacement of the product line; the possibility of installing the dispenser in the conveyor line; construction of multi-channel dosing systems; absence of intraoperative drop formation; compactness, simplicity and safety of maintenance; fire and explosion safety, etc.

Therefore, the tasks of developing valveless airlift systems for dosing and packaging of liquid products are relevant.

II. LITURATURE ANALYSIS

The processes of food, chemical, textile, perfumery and many other industries are based on operations of metered supply of liquid products. For example, in work [1-27], the costs of the product, which are established by the technological regulations, are investigated. The authors describe a process control system based only on the contours of the automatic adjustment of one dosing parameter. The issues of development and implementation of aerial mechatronic dosing systems with tracking circuits for two or more technological parameters remain unresolved. Critical analysis of liquid food product dosing systems is based on electropneumatic systems and is complicated by the lack of ready-made industrial executive modules. In particular, in [2] dosing devices for small dose ranges. The analysis of the task of automating technological processes of aerial dosing, in work [3], describes the design of servo-pneumovalves. This description is even more complicated because the control object has an inertial delay and parametric non-stationarity. The results given in [4] can be a solution to overcome the relevant difficulties. In this case, a high-quality organization of dosing processes is possible only when closed systems of automatic regulation are used. Such tasks require the development of universal automatic dosing systems, which are functionally adapted to perform both batch and continuous dosing operations. [5,6] Complex tasks for the formation of multicomponent emulsions, as the authors note, are a relevant direction in the development of synergy of water purification systems with elements of dosing systems. The issue of dosage accuracy is also relevant. Despite the fact that in the work [7-9], the authors described the data of the analysis of pure water and impurities added to it, but the results do not give recommendations for the design of the dispenser.

The text of the source [10-11] describes data on the dosing process with an analysis of the reliability parameters of technological elements. Pneumatic valves and product line connection systems are described, but the results are not complete. The dosing principle, described in [12], is time-oriented with the condition of ensuring a constant flow of liquid. Unfortunately, the results of the conducted experimental studies do not describe the energy consumption of the dosing system [13-17]. Therefore, there are reasons to assert the expediency of conducting a study devoted to the construction and testing of liquid product dosing systems based on electropneumatic complexes.

And also, according to the method of empirical research, to obtain results for the analysis of the process of forming the dose of the product for the airlift dispenser system and the study of further dosing accuracy.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The object of the research is an in-house developed manipulator-dispenser of the airfoil type for liquid food products. The subject of the research is the processes of formation and release of the product dose in the airlift type system.

The purpose of the research is mathematical and physical modeling for the process of aerial dosing of liquid food products. For this, the search for initial

conditions and assumptions is proposed. This provides calculations for the further development of a functional airlift dosing module without dose shut-off valves and piping fittings.

The research objectives are as follows. Investigate the process of formation and subsequent extrusion of the dose of the product from the dosing receiver. Analytical description of individual stages of the dosing process and further analysis of individual stages and accepted assumptions. Determining the influence of individual parameters on the accuracy of product dose formation, as well as finding ways to ensure the necessary distribution of compressed air pressure under the conditions of compliance with the specified performance of the dispenser. Development of a stand for the study of a functional dosing module with software-set modes of product dose formation and displacement.

Research methods. The experimental theoretical studies performed were based on the application of fundamental laws for the hydrodynamics of liquid media and viscous fluid media, the general theory of solving ordinary differential equations, the theory of 3D modeling, and the mathematical statistical theory of experimental data processing.

The research is based on the static and dynamic characteristics of the control system of the dosing device with the analysis of the choice of design parameters of the equipment, which is aimed at improving the metrological characteristics of the automated airlift dosing system.

Schematic diagrams of universal dosing devices and dosing control algorithms were developed to prepare experiments that ensure the implementation of various laws of product dose formation. The assessment of systematic errors was carried out in the Excel package for the proposed method of batch dosing. The batch system of automated dosing, based on the principles of the airlift system and works [3, 5, 8, 11-26], is described by the mathematical model of the description of the dosing process, the scheme of the experimental setup and is described below.

Experimental studies of processes of precessional dosing of liquid products based on electropneumatic complexes, carried out taking into account numerical methods; hydrogas dynamics; copyrights.

IV. RESULTS

4.1. Experimental stand

The installation diagram of a valveless electropneumatic dosing device with a control module is shown in Fig. 1. The diagram in Fig. 1 contains a pneumatic control system (CP) 4 for processing pressure signals about PP (pi) and DE (p) in a programmable logic controller (PLC). Control signals are generated on the executive pneumovalves of the dispenser -5, 6, 7 and 8. In fig. 1, a valveless electropneumatic dosing device for an airlift type of dosing tank system is given. The solution refers to pressure-type dosing systems. The feeder tank (PP) 1 has a liquid level sensor 2, formed with a system for pushing out the product into the dosing receiver (DE) - 3.

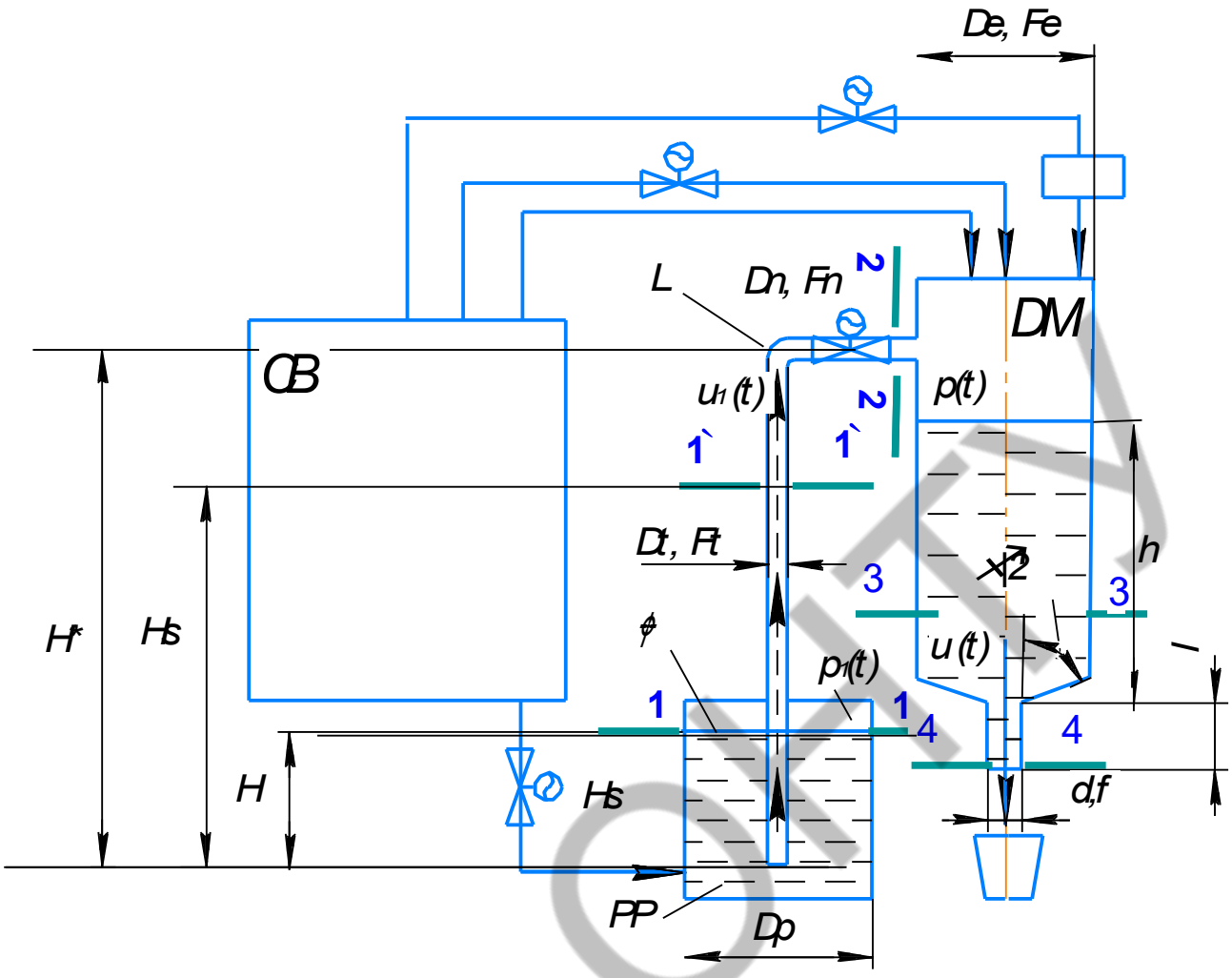


Fig. 1. Installation diagram for a valveless electropneumatic dosing device of an airlift type system with a control module: 1 - loading hopper, 2 - product supply area by auger, 3 - vertical transport channel; 4 - product, 5 - compressed air; 6 - gas suspension (air, fine-grained product), 7 - electropneumatic control unit; P - main pressure of compressed air (MPa), 2P - double the pressure at the booster outlet; 1.1., 1.2. - reed switches; l1, l2 - length of the acceleration section and stabilization section (m)

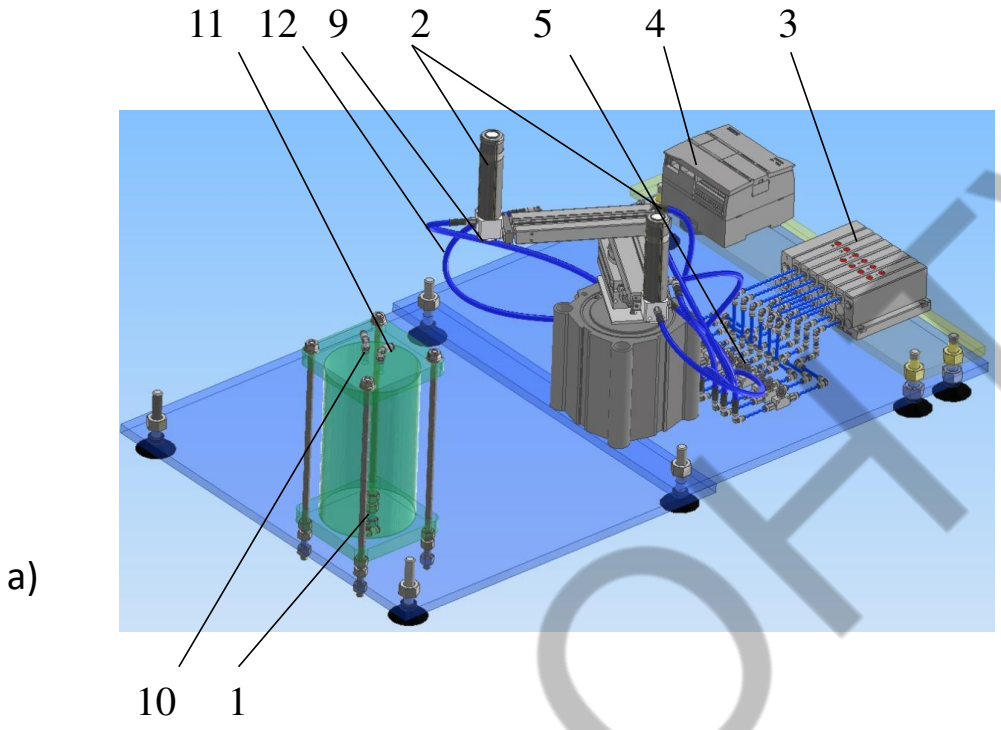
PP with a level sensor, DE and executive pneumatic valves of the DU are the basis for the OU control object. The pressure control system for pushing out the dose in the dosing receiver works on a combination of the control system with feedback (current loop format 4..20 mA). The control signal can also be adjusted according to the current on the solenoid of the distributor by supplying compressed air to the remote control with a range of 0..5s.

The principle of operation of the dispenser is based on the software control of the pressure supply to the system of the dosing receiver from PP with the DE mounted above it at a height of H*y. The dose of the product is formed through the drain pipe 9 (DE) due to the change in pressure in the DU system and with the help of an ejector.

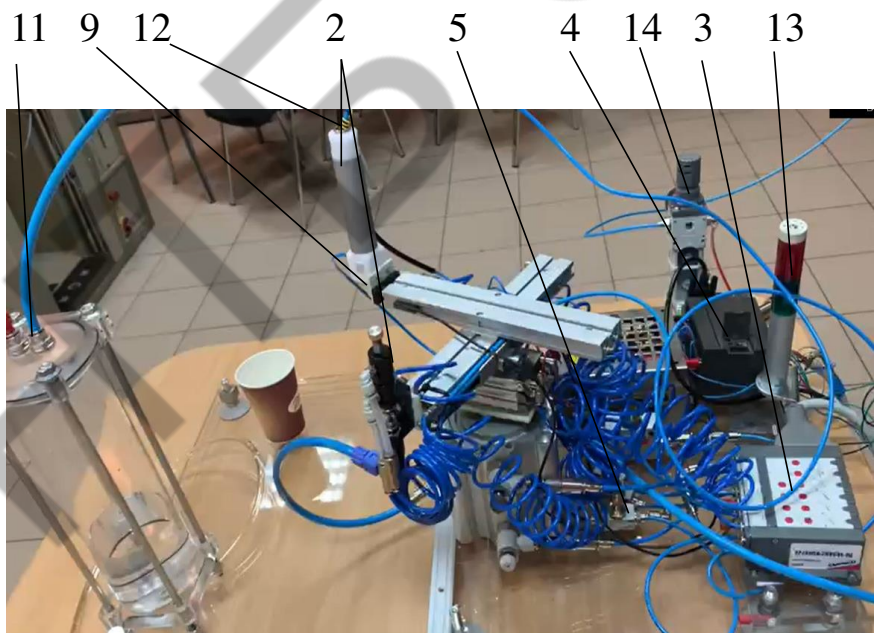
The dosing process is controlled within the limits of the pressure P in a closed gas medium of variable volume, and is accordingly ensured in the process of product outflow. At the beginning of the operation of the dosing module, the DE is connected

to the channel 10 of the power source through the open valve 7. At the same time, blowing with compressed air for the drain pipe 9, the inlet pipe 11 and the connecting pipe 12 is turned on. Such actions maintain the cleanliness of the product line of the dispenser until the start of the next dosing cycle.

DU the remote control is in the dosing mode, and at this time, the command-programmed pressure change in the control device from the PLC is carried out



a)



b)

Fig. 2. Type of the experimental stand for the study of the airlift system for dosing liquid products: a) – general view of the experimental stand 3D; b) – general view of the dosing manipulator module after installation; 1 – waste tank; 2 – dosing and packaging module of the membrane type; 3 – a pneumatic island with a set of executive control valves (electromagnetic distributors 3/2NO, 5/3, 5/2) with a pneumatic signal;

4 – control system (PLC); 5 – executive pneumovalves of the doztor; 6 – module for linear movement of dispensers (2 tandem cylinders with anti-rotation platform; 7 – rotary cylinder; 8 – module for vertical movement of the manipulator (linear cylinder is equipped with sensors and reed switches); 9 – drain nozzle; 10 – power source channel with ejector; 11 – inlet nozzle 12 – connecting pipeline); 13 – signal lamp; 14 – compressed air control and preparation unit

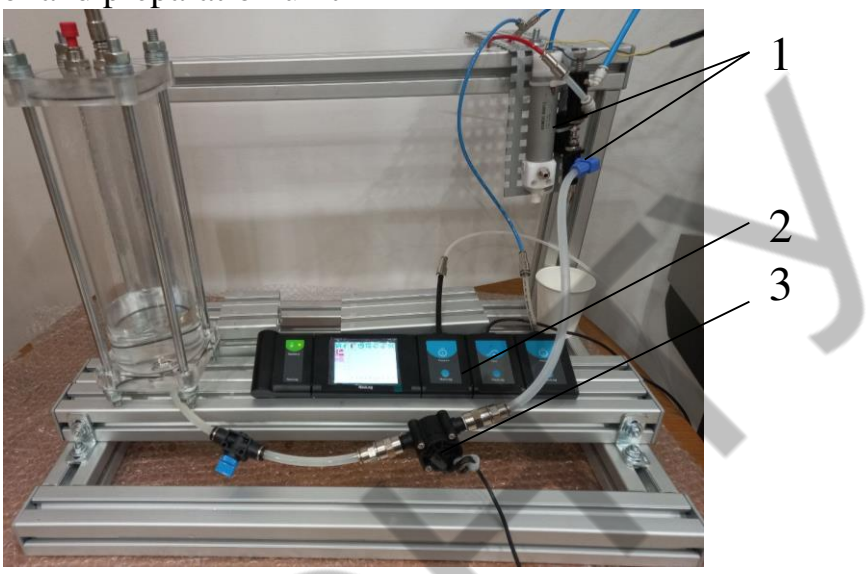


Fig. 3. Elements of the control system: 1 – dispenser; 2 - analog-digital measuring complex (flow sensor, pressure sensor, signal processing system); 3 – flow-mirror type

The dosing cycle is based on the stages of product filling of the pipeline 12, partial filling of the DE and displacement of the product, with the setting of the UE purging mode. The operation of the DU involves fixed values of the design parameters: nozzle and outlet cross-section of the nozzle, through-sections of the product line, the length of the compressed air supply pipeline and the full volume of the DE, the height H* for the installation of the DE. Therefore, the time constant PZ and pressure for the power source 10 and the size of the dose volume Vd will be a function of the pressure formed for the ru dispenser and for the initial filling level of PP – H0. We also obtained a function with the condition of a constant H0 value to ensure the working tare characteristics of the dosing module. The function describes the error for fixed values of py during the change of the initial filling level of PP. On the basis of the conducted experimental research, the error values are set within the limits of ±1%.

To analyze the conditions for ensuring the accuracy of dosing, the design of the experimental stand of DU was developed (Fig. 3). We will consider the flow of the product in the connecting pipeline (from RR to DE) with the analysis of movement through the drain nozzle of DE in the system of unsteady one-dimensional turbulent motion of a Newtonian fluid. The impact of various factors on dosing accuracy was evaluated with accepted assumptions. The comparison of different stages of dosing during the operation of the DU was carried out under the condition of a constant pressure value, which is programmed for the Ru doser.

4.2. Mathematical model

At the stage of filling the connecting pipeline, we will describe a system that contains two equations for the variables s (t) and H (t), where s (t) is the current level

of the liquid in the pipeline, H (t) is the current level of the liquid in the PP.

The equation of motion for the free surface of the test liquid in the connecting pipeline, according to the Bernoulli equation for unsteady motion for section 1 - 1, which coincides with the position of the liquid level in the RR, and section 1'- 1', and coincides with the liquid level in the assembled pipeline at a distance s from the inlet edge for the pipeline:

$$s(d^2s/dt^2)+\frac{\lambda_T}{2D}s(ds/dt)^2+\frac{1+\xi_T}{2}(ds/dt)^2+gH_s(s)=\frac{p_1(t)}{\rho}+gH(t). \quad (1)$$

During the simulation, there are additional assumptions: Hs(s) is the height of the section 1' - 1' as a function of the parameter s, which depends on the configuration of the connecting product line; DT is the diameter of the connecting pipeline;

$$p_1(t)\cong p_{1,з}(t)=P(1-e^{-t/\tau_0}),\text{—} \quad (2)$$

$p_1(t)$ – the actual pressure in the RR as a function of time t under the condition of the ideality of the programmable RD pressure regulator; $p_{1,3}(t)$ $p_{1,з}(t)$ – set value of the adjustment parameter; $P=const$ – supply pressure of pneumatic elements of UU; τ_0 – the software time constant, which depends on the conditions of the surrounding environment; ρ - product density; $g = const$ – acceleration of gravity; $\xi_T = const$ – coefficient of local resistance at the entrance to the product line, which depends on the configuration of the entrance edge of the pipeline; λ_T – the coefficient of friction in the pipeline depends on the Reynolds number $Re_T = \rho D_T(ds/dt)/\mu$, is calculated by the Blasius formula:

$$\lambda_T=\frac{0{,}316}{(\mathrm{Re}_T)^{1/4}}=\frac{0{,}316}{(\rho D_T(ds/dt)/\mu)^{1/4}}, \quad (3)$$

coefficients α_{1-1}; $\alpha_{1'-1'}$ take into account the non-uniformity of the distribution of velocities in the sections 1- 1; 1'-1', we take as equal 1; μ - dynamic viscosity of the product, which depends on temperature. During the formulation of equation (1), a number of assumptions were made: from equation (1), we neglect (insignificant values) the product velocity coefficient in the RR and take the cross-sectional area of the RR and the connecting product pipeline: $\Omega = \pi D^2_P/4$; $F_T = \pi D^2_T/4$ – area of RR cross-sections and connecting pipeline.

The balance equation of fluid flow from RR is as follows:

$$-\Omega(dH/dt)=F_T(ds/dt).. \quad (4)$$

The system of equations (1) and (4) is solved according to the initial conditions: $s(0) = s_0 = H_0$, $(ds/dt)(0)=(ds/dt)_0=0$; $H(0) = H_0$. The result of solving this system is the value of the function $s(t)$ provided the time is determined τ_T product filling of the connecting nozzle and initial speed $u_{1,0}$ introduction of the product in DE. Provided the value is known $s(t)$ parameters τ_T, $u_{1,0}$ are defined as:

$$s(\tau_T)=L;\ u_{1,0}=\left(ds/dt\right)\big|_{t=tT},, \quad (5)$$

L – pipeline length.

The stage of filling the DE drain pipe determines the initial conditions of the next stages of the dosing process - the outflow of the product in the outlet section. Given the small size of the nozzle, in particular its length l and the empirical value of the

optimal ratio of the inlet pipe diameters D_n for DE and nozzle *(d) - $D_n/d \geq 1,7$* we accept the condition that the inflow of the product into the DE at each moment of time exceeds the consumption through the section of the nozzle with the following conditions:

$$u_1(0) = u_{1,0}; H(0) = H_0^* = H_0 - F_T L; p(0) = p_0 \cong 0; h(0) = h_o \cong 0;$$
$$v(0) = v_0 \cong 0; u(0) = u_0 = \sqrt{2gl}\ ; p_1(0) = p_{1,0} = P(1 - e^{-\tau/\tau_0}), \quad (6)$$

where $u_1(t)$ – speed of movement in the product pipeline, $H(t)$ – the current value of the product level in RR; $p(t)$ – pressure in the DE gas space during filling; $h(t)$ – product level in DE; $v(t)$ – the volume of the filled part of the DE without the volume of the drain nozzle; $u(t)$ – the flow rate of the product through the nozzle.

Note that the outflow of the product is carried out through the section of the nozzle and is described by conditions (6). The equation of motion of the product in the connecting pipeline is represented by the Bernoulli equation for unsteady motion, according to constraints 1–1; 2–2, taking into account the condition of the equality of the diameters of the product line and the DE inlet pipe *($D_T=D_P=D$, $F_T=F_P=F$)* will look like:

$$\frac{p_1(t)}{\rho g} + H = \frac{p(t)}{\rho g} + H^* + (1 + \xi_T + \lambda_T \frac{L}{D}) \frac{u_1^2}{2g} + \frac{L}{g} \frac{du_1}{dt}, \quad (7)$$

$$p_1(t) \cong p_{1,з}(t) = P\left(1 - e^{-(t+\tau_T)/\tau_0}\right), \quad (8)$$

the pressure in the RR is a function of time t under the condition of ideality of the software pressure regulator of the RD; λ_T – coefficient of friction in the pipeline, which depends on the Reynolds number $\mathrm{Re}_T = \rho D u_1 / \mu$, which is calculated by the Blasius formula: $\lambda_T = 0,316 / (\mathrm{Re}_T)^{\frac{1}{4}} = 0,316 / (\rho D u_1 / \mu)^{\frac{1}{4}}$. (9)

Similarly to equation (1), in equation (7) coefficients α_{1-1} та α_{2-2} , take into account the unevenness of the speed distribution in sections 1–1 and 2–2. The specified coefficients are assumed to be constant and equal to 1. Also, we ignore the equal component $\alpha_{1-1}(F/\Omega)^2 (u_1)^2 / 2$, which takes into account the pressure velocity in RR.

Accordingly, for periods 3–3 and 4–4, the product flow equation is also based on the Bernoulli equation:

$$\frac{p(t)}{\rho g} + l + h + \frac{(\frac{dh}{dt})^2}{2g} = \left(1 + \xi_n + \lambda_n \frac{l}{d}\right) \frac{u^2}{2g} + \frac{l}{g} \frac{du}{dt}, \quad (10)$$

λ_n – coefficient of friction inside the nozzle; ξ_n – nozzle inlet resistance coefficient, α_{3-3} та α_{4-4} – speed distribution coefficients in these sections are equal to 1. Then, the cost balance equation in DE:

$$\frac{dv}{dt} = u_1 F - u \cdot f, \quad (11)$$

$v=v(t)$ – fluid volume in DE. Consider the equation of the gas state in DE:

$$v = V_0 p / (P_a + p), \quad (12)$$

V_0 – DE volume, taking into account the volume of connecting channels, except for the drain nozzle, P_a – atmospheric pressure. Equation (12) corresponds to the isothermal compression of gas in the DE system, subject to the inequality: $P_a \square \ p_0 \cong 0$. p_0 – excess air pressure in DE at a moment in time t=0, this is the period of completion of product filling of the cross-section of the DE drain nozzle.

The equation of the balance of product costs in DE will look like this:

$$-\Omega\left(\frac{dH}{dt}\right) = u_1 F. \tag{13}$$

The equation of the relationship between the volume and the level of the product in DE:

$$v = \left(\frac{1}{3}\right)\alpha_1 h_3 + \left(\frac{1}{2}\right)\alpha_2 h^2 + fh \text{ provided } h \le h_k, \tag{14}$$

$$\mathrm{P}\, v = \left(\frac{1}{3}\right)\alpha_1 h_3 + \left(\frac{1}{2}\right)\alpha_2 h^2 + fh \text{ provided } h \le h_k, \tag{15}$$

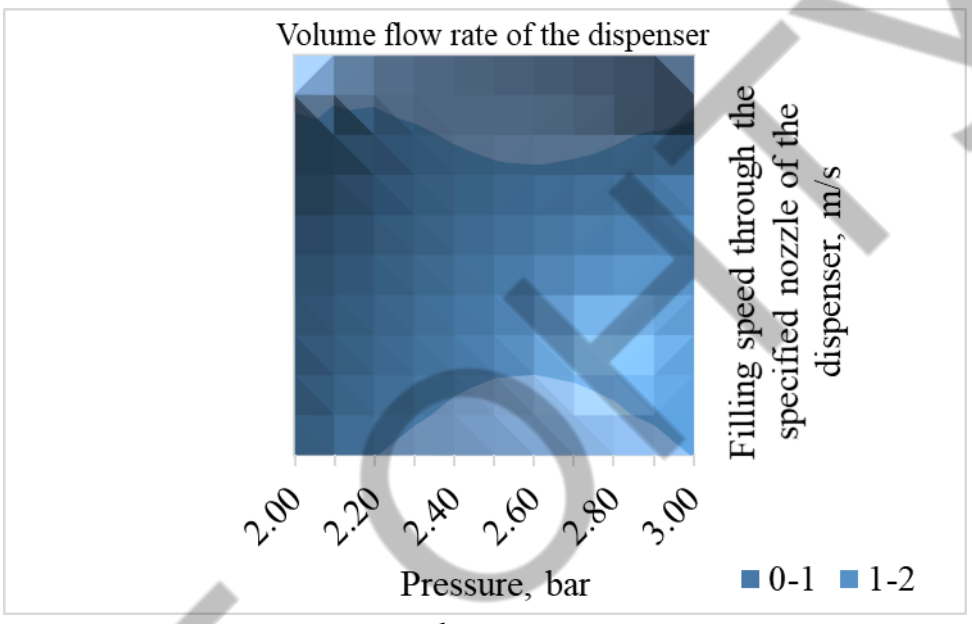
in accordance $\alpha_1 = \pi tg^2\left(\frac{\varphi}{2}\right)$, $\alpha_2 = \pi dtg\left(\frac{\varphi}{2}\right)$, h_k – height of the lower conical part of DE; $F_e = \pi\frac{D_e^2}{4}$ - the area of the cylindrical section DE. Ejection of the dose of the product and the subsequent process of switching to the purging mode using the ejector occurs according to the established algorithm and is achieved by bringing the pressure to the programmed value p_y. The process is accompanied by the opening of valves 5 and 7; at the same time, the pressure in DE increases from the value p_y to a value equal to the supply pressure R. A pressure p_1 in RR decreases from p_{1vd}, (moment of dose cut-off) to zero. Under the action of pressure P, the DE is completely emptied. After the end of the process, the pressure p in the DE is reduced due to the removal of air into the atmosphere through the drain nozzle. Considering the small volume of DE - V_o and nozzle length – *l*, its complete emptying occurs significantly earlier than in the connected pipeline, as well as before the pressure drops to zero p_1 in PP.

4.3. Study of a precision dosing system for liquid products based on electropneumatic control systems.

In fig. 3 shows the results of the conducted experiment according to the algorithm for changing the pressure in the feeder tank of the dispenser from excess to vacuum pressure, in accordance with the developed plan of the drinking water dosing experiment. After summarizing the results of the conducted experiment in Excel, the results in Fig. 3 are obtained:

Pressure, bar	liquid packing speed, m/s											
	2.00	2.10	2.20	2.30	2.40	2.50	2.60	2.70	2.80	2.90	3.00	
1.01	1.549085	1.816005	1.986552	2.114573	2.217987	2.302047	2.365695	2.4018	2.392185	2.290753	1.967815	1.01
1.01	1.368643	1.628882	1.816276	1.954489	2.056099	2.12526	2.159621	2.149897	2.076624	1.903288	1.568617	1.01
1.01	1.285104	1.515393	1.696185	1.832147	1.92785	1.984429	1.998679	1.962419	1.861784	1.677567	1.391514	1.01
1.01	1.245026	1.452406	1.622199	1.751506	1.840221	1.887382	1.889559	1.84041	1.73134	1.554187	1.308049	1.01
1.01	1.231328	1.428146	1.590137	1.713083	1.795833	1.836953	1.833237	1.779547	1.669892	1.500348	1.274687	1.01
1.01	1.240911	1.439903	1.598621	1.716543	1.794827	1.833051	1.828413	1.775914	1.669273	1.503198	1.27854	1.01
1.01	1.281168	1.493088	1.649354	1.761273	1.835571	1.873647	1.87292	1.827639	1.728989	1.565177	1.324454	1.01
1.01	1.37936	1.602974	1.745748	1.845098	1.914062	1.954513	1.963302	1.933826	1.854675	1.704552	1.442253	1.01
1.01	1.621877	1.794576	1.88666	1.960535	2.022331	2.06826	2.09304	2.090591	2.051995	1.956502	1.728125	1.01
3.32	2.302008	2.067451	2.046599	2.08896	2.147406	2.204059	2.250815	2.284166	2.306698	2.341622	2.50183	3.32
2.36	2.196981	2.127027	2.143827	2.20186	2.274844	2.350301	2.422479	2.488956	2.549298	2.601623	2.615613	2.36
	2.00	2.10	2.20	2.30	2.40	2.50	2.60	2.70	2.80	2.90	3.00	

a



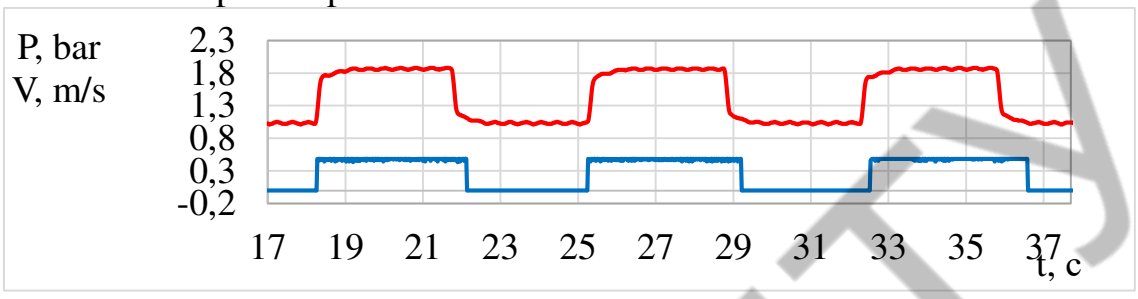
b

Fig. 3. Characterization of changes in the main parameters of dosing and pressure control in the airlift functional mechatronic dosing module system under the condition: a) according to tabulated average data of dosing experiments; b) change in pressure in accordance with the change in flow rate in the vector field with determination of extrema

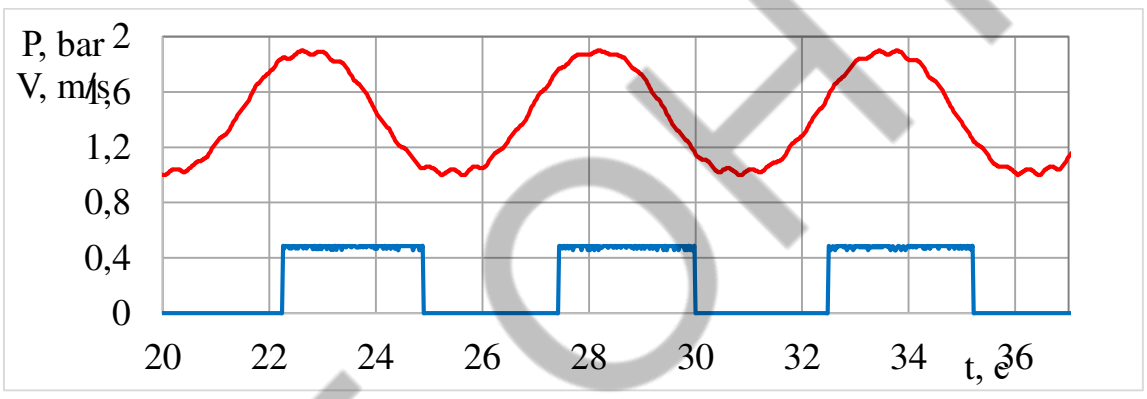
Stationary mode is determined by air speed and pressure, which remain constant during the operation of the installation, taking into account the mode of transportation. Air speed and pressure at the inlet are the main conditions for the start of the product dose selection (extrusion) stage. The first stage of Fig. 3, a, b shows the output of the installation to the stationary mode of product extrusion when compressed air is supplied to the system within the software-defined range of pressure changes in the range from 0.99 to 1.81.

4.4. Characterization of the laws of controlling the parameters of the functional mechatronic module of aerial dosing with a change in pressure in the product line. The range of pressure change was chosen by the method of sorting, based on the main monitoring of the change in the flow rate in the system (0.5 m/s) and the accuracy of the allocated dose (50 ml): As the compressed air accumulates in the supply receiver, the speed and pressure stabilize, the dosing accuracy increases by 2 % (Fig. 4, a, b). (Addition A) The second stage of research, the results of which are shown in Fig. 4, is

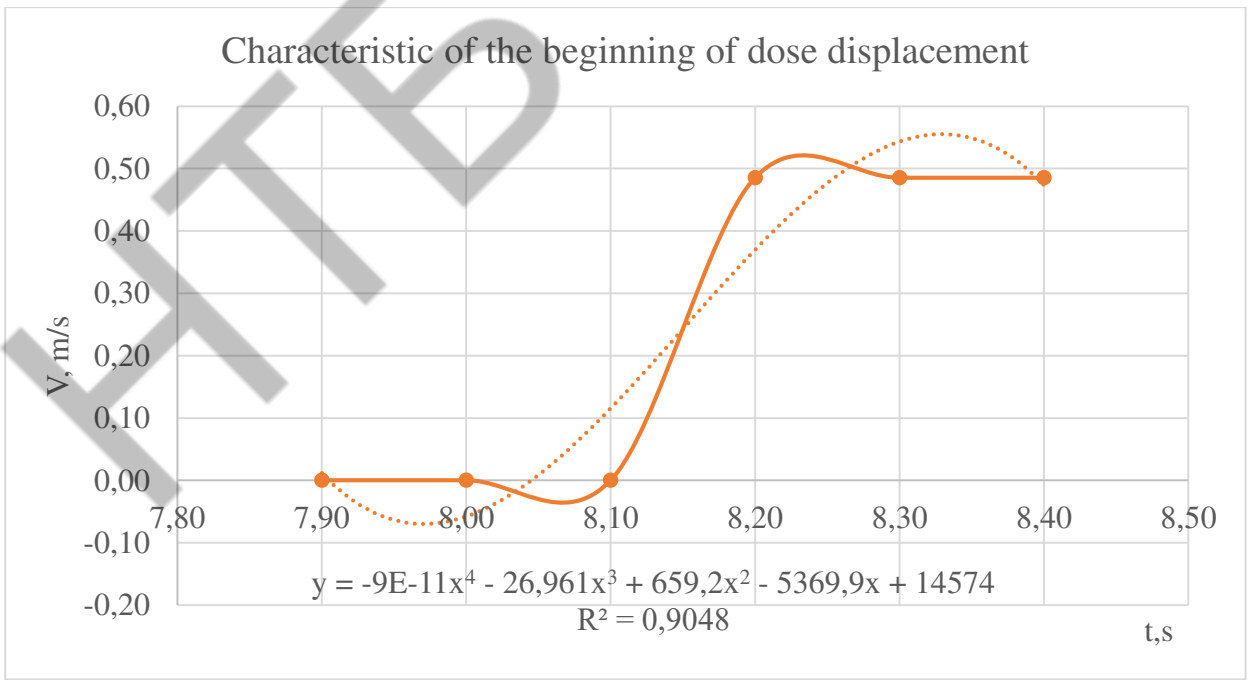
related to the monitoring of the working zone of changes in the parameters of the speed of movement of the dosed product in the pipeline. Acceleration is determined by a time interval of 0.1... 0.3 s and depends on the established compressed air supply control modes. Measurements were carried out using a turbine-type digital flow meter. In fig. 5, b clearly shows the distribution of the linear speed of the movement of the fine-artificial product when moving in the channel of the product pipeline under pressure. This confirms the results of modeling [7], regarding the influence of local resistances on the increase of specific pressure losses.



a



b



c

Fig.4. Characterization of the laws of controlling the parameters of the functional mechatronic module of airlift dosing with a change in pressure in the product pipeline under the condition: a – change in pressure and flow rate in the output product pipeline

during the influence of the control signal according to the step law; b – change in pressure and flow rate in the output product line during the influence of the control signal according to the sinusoidal law; c – the results of the experimental data are worked out in Excel by a polynomial of the 4th degree

As a result of working out the experimental measurements, the data characterizing the dosing and packaging process was obtained within the specified error of up to 2%. The value of the approximation reliability coefficient is 0.9.

V. CONCLUSIONS

The obtained results are explained, first of all, by the fact that the shape of the working channel of the product line and the diametrical cross-section of the working channel for the supplied and squeezed product from the dosing receiver are taken into account. As the time of the dosing process increases, the compressed air in the product line stabilizes and the accuracy of the product dose improves significantly.

Stationary mode is determined by air speed and pressure, which remain constant during the operation of the installation, taking into account the mode of transportation. Air speed and pressure at the inlet are the main conditions for the beginning of the stage of selection (extrusion) of the product dose. The results of the pressure change at the inlet and outlet of the product line are shown in (Fig. 3–4), due to internal pressure fluctuations of 20 Hz for 1 cycle of pressure supply. This mode of air supply is organized by the driver. Taking into account the purpose of the conducted research, which also takes into account the physical modeling of the airlift dosing process of liquid and low-viscosity food products. the initial conditions for further development and research of the operation of the functional mechatronic module of airlift dosing without dose cut-off valves and elements of pipeline fittings are defined. So, in particular, the error of dosing accuracy when using the step law of controlling the change in pressure in the dosing receiver system is 0.8% of the set dose of 50 ml; and when using the step law, the pressure change control in the dosing receiver system is 0.3%. The obtained modeling results allow, through physical modeling, to obtain initial parameters for mathematical studies, to describe the dependence of the main kinematic parameters of product dosing and to predict the drop and compensation of pressure in the dispenser system. The following parameters were introduced as limitations of the research results. current control value, relative to the standard scale, Imax..Imin = 4.1..19.9 mA, the frequency of compressed air pulses in the product line - 0.1... 7 s. Previously, the value of the control signal formed the maximum pressure in the pipe of 0.1... 0.5 bar. This confirms the results of the work [20, 22] and determines the optimal dosing regimen of the product under study. The limitations of the conducted studies can be considered that they were conducted only for liquid products from the group of Newtonian media. The lack of complete experimental data for other types made it impossible to carry out a more detailed analysis of the effectiveness of the developed design of the functional mechatronic module of airlift propulsion and its calculation methodology. Especially, this would be relevant for mixing products (suspensions, emulsions) with particles of different diameters (up to 1 mm or more), for which the curvature of the working channel in the diametrical cross-section of the product line can become a condition for influencing the accuracy of dosing.

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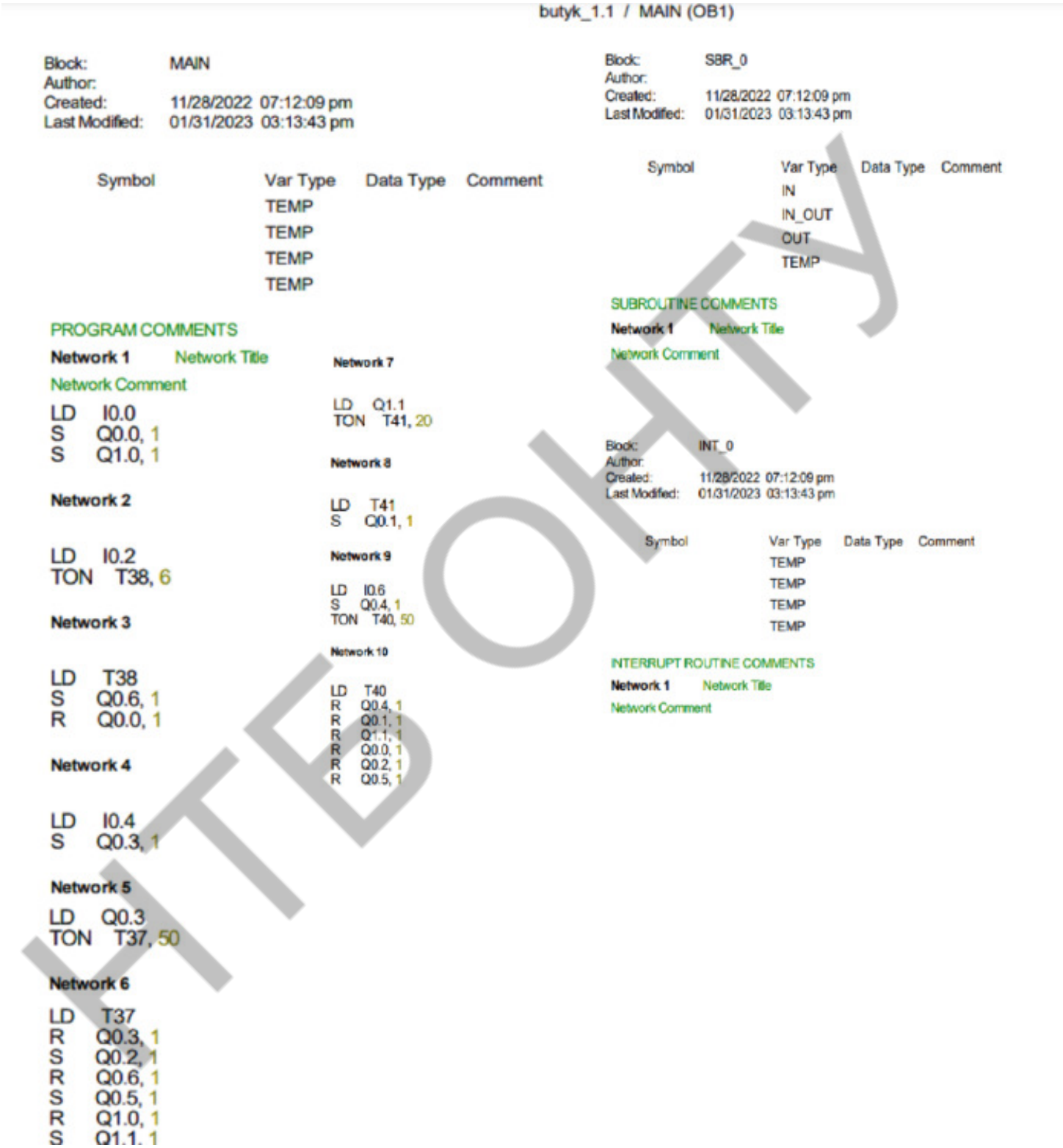
Addition A



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	TEMP		

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Network 2

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Network 3

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S    Q0.6, 1
R    Q0.0, 1
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Network 4

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S    Q0.3, 1
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Network 5

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TON  T37, 50
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Network 6

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R    Q0.6, 1
S    Q0.5, 1
R    Q1.0, 1
S    Q1.1, 1
```

Network 7

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LD   Q1.1
TON  T41, 20
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Network 8

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LD   T41
S    Q0.1, 1
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Network 9

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S    Q0.4, 1
TON  T40, 50
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Network 10

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	TEMP		
	TEMP		

INTERRUPT ROUTINE COMMENTS

Network 1 Network Title

Network Comment

2. ECONOMICS AND ADMINISTRATION

PROMOTION AND ANALYSIS OF PERSONAL BRAND IN THE SOCIAL NETWORK INSTAGRAM

Authors: Oleksandr Tsymbaliuk
Olha Smyk
Advisor: Anna Pavlyk
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Abstract. *The scientific work aims to determine the main elements of the possible use of Zizi_zay_'s personal brand for the successful development of a business account.*

The following research methods were used when writing the scientific paper: marketing research methods (desk and field researches, SWOT Analysis of the personal brand, its analysis according to the 4Ps of the Marketing Mix, the Three Product Levels), personal brand audit (competitor analysis, account analysis, and brand analytics Zizi_zay_), primary methods of information collection (online survey), graphics (construction of a polygon of brand competitiveness and sales funnel), and the algorithm of its promotion in social networks are described.

The object of the study is the personal brand account Zizi_zay_.

Subjects of the study: consumers of the author's products and their competitors.

The subject of the study is innovative tools and strategies for business promotion in the Instagram social network.

Scope and structure of work. The scientific work consists of an introduction, two chapters, conclusions, and a list of references. The total volume of work is completed on 15 pages of printed text, which contains four tables and seven figures. The list of used sources includes ten names.

The scientific novelty consists in improving approaches to the use of communication tools and promotion strategies in the Instagram network at the stage of business growth.

The practical significance of this work is that the given recommendations are valuable and promising, so the Zizi_zay_ brand can implement them in practice.

Keywords*: Brand-wheel, engagement rate, amplification rate, conversion rate, click-through rate, funnel, audience growth rate, post outreach.*

I. INTRODUCTION

The actuality of the theme. A personal brand is a leading brand in our life. This is a brand based on a professional position. This is a stable image and reputation, which is postponed in the consciousness of society about a person. Creating a strong personal brand is authentic. It must have sales offers and reviews that build reputation, meet the target group's needs and constantly monitor strategic positioning.

Today, social network development has formed a new channel of communication between the personality, the brand, and the client. The better this connection is, the easier it will be to promote business. Sales on the Internet are gaining more and more volumes, and this segment is developing rapidly compared to others, despite the crisis, exchange rate changes, the pandemic in the world, the war in

Ukraine, etc. It is worth noting that there was a significant increase in user pages on the Instagram network, both personal and business accounts, so their audience increased accordingly. This positive factor allows using this brand to communicate more easily with the client and increase their loyalty.

Therefore, a personal brand is one of the essential components for successful business development.

II. PERSONAL BRANDING IS ONE OF THE WAYS OF BUSINESS DEVELOPMENT

2.1. Theoretical and methodological aspects of personal brand formation

A personal brand is a trend of recent years that will influence business and career development in the 21st century. Reputation management is necessary for every person: an office worker - to facilitate the job search, a blogger - to attract followers and interest in the company, and a creative worker - to find more orders. A business person must create a personal brand to increase marketing potential and create a professional image. A personal brand creates a strong connection between a person and his mission, business, or competence. It also brings recognition and therefore provides a competitive advantage in the market.

Personal branding expert Peter Montoya says building a personal brand is hard work. It is essential to understand that everyone has a personal brand, but not everyone has an effective brand. In his book The Personal Brand Phenomenon, Peter Montoya formulated eight laws of personal branding; the law of specialization, the law of leadership, the law of individuality, the law of separation, the law of constant presence, the law of loyalty to the original brand message, the law of persistence, the law of a positive note [9].

"Brand wheel" is a well-known and affordable tool for creating a brand for those who make independent decisions regarding the promotion of the enterprise. Brand-wheel, developed by the British company Bates Worldwide, is considered one of the world's most popular and successful brand-building tools. According to this model, the brand can be represented as a set of circles, each of which represents a separate element (fig. 2.1.) [8].

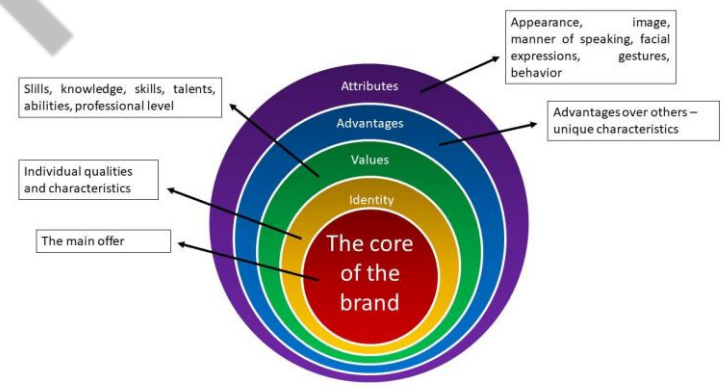

Fig. 2.1. «Brand-wheel»

Source: [8]

Components of "brand wheels": brand attributes, brand benefits, brand value, brand identity, and brand essence. However, this does not consider that the brand's

success is influenced by external factors: the competitive environment and the product positioning process.

2.2. A personal brand is the way to success

At the center of the personal brand is the young creative personality of Olesya Ivasechko, a needlewoman from Ternopil who creates exclusive children's toys with her own hands. To promote and sell her works, she made a social page on Instagram and began receiving the first orders. It used to be just a hobby, but now, thanks to posts, high-quality photos, and clever marketing, he successfully sells his products on the Internet. Handmade is a great opportunity to show creativity, emphasize individuality, get satisfaction from work, and get rewarded for your work.

The logo is one of the essential elements of identity, which will help:

Increase the recognition of a personal brand, identify products, evoke specific associations and emotions in the target audience, increase the loyalty of regular customers, facilitate communication with potential customers, create a particular image and reputation, and increase brand popularity.

In the center of the logo is a bunny, which is harmoniously combined with the word zay - the name of the page and a lullaby, which indicates the brand's operation in the children's products market. In the background, there is a figure of yellow color, which symbolizes the greatness of the power of the Sun - a symbol of protection and hope. In the Middle East, it is considered the color of success and prosperity; in Japan - a symbol of courage and aristocracy; in India - profit and prosperous trade.

A logo is a visual trigger that evokes specific associations in a person's memory, and a person unfamiliar with the brand has loose associations that depend solely on personal experience. In the case of the coincidence of free associations and the brand's image, "chemistry" occurs - the client likes it and makes a purchase decision.

The logo is a graphic representation of the brand's essence, and the slogan is its mission. The main feature, aimed at increasing the number of buyers, is laid in the content of the saying "Made with love" that is, quality, safe, ecological products for children are sold under the brand name Zizi_zay_ (fig. 2.2.).

Fig. 2.2. Personal brand logo Zizi_zay_

Source: [5]

To choose a future development strategy, a SWOT analysis of the personal brand of Olesya Ivasechko was conducted (tab. 2.1.). SWOT analysis is a simple self-assessment tool and, at the same time, ideal for assessing the chances of entrepreneurial activity. SWOT analysis is a mini-tool that will help achieve a goal, strengthen strengths and eliminate weaknesses, use potential opportunities, and control threats [3]. The above analysis showed that the Zizi_zay_ brand has a sufficient number of

competitive advantages, which allows it to conduct a successful business and obtain economic benefits.

Table 2.1. SWOT analysis of the personal brand of Olesya Ivasechko

Strengths	**Weaknesses**
▪ Acquisition of a manager's profession ▪ Basic knowledge of economics and marketing, IT skills ▪ Participation in the advertising festival (USFR) ▪ Purposefulness, friendliness, sociability, punctuality ▪ Skills in various needlework techniques ▪ Ability to create original works in handmade style ▪ Creative personality	▪ Limited financial resources ▪ Anxiety before public speaking ▪ Lack of car and driver's license
Opportunities	**Threats**
▪ Opening of the online and offline store "Toy Workshop." ▪ Expansion of product range and geography of sales of goods ▪ Activation of the advertising campaign on social networks ▪ Participation in master classes, training ▪ In plans to become a marketer	▪ Strengthening the positions of competitors ▪ Decrease in the birth rate ▪ Changing consumer needs and tastes ▪ Decrease in purchasing power ▪ Change in regulatory legislation ▪ Increase in prices for raw materials and energy resources

Source: compiled by the authors according to [5]

After analyzing the personal brand of Zizi_zay_ according to the 4Ps of the Marketing Mix: Product, Price, Place, and Promotion, we get the following results:

Product. The assortment line of the Zizi_zay_ brand has 26 items, which allows for meeting customers' needs on time. The next step of the research is the analysis of competitors. For this purpose, a survey was conducted among young mothers on social networks. The main competitors for the brands are Fetrova_kira and fairyshop. Mobiles were evaluated according to the following criteria: saturation of the assortment, affordable price, advertising support, and the number of subscribers, using a 10-point scale. A competition polygon was built for the entire understanding of the place of the Zizi_zay_ brand in the market segment, taking into account the positions of competitors (Fig. 2.3.).

The analysis of competitors in social networks showed that all personal brands have good content on the page important for the user (saturation of the product range, reviews, interesting articles, prices) and attractive design. In the information circle, the Fetrova_kira brand occupies a leading position according to the criteria: the number of subscribers, saturation and creativity of the product range, advertising support, and the presence of a toy studio and an online store. Fetrova_kira and Zizi_zay_ personal brand pages are modern, bright, and informative, with good content, design, and video content. The brand fairyshop.mobiles is easy to use, low occupancy, small assortment, and insufficient advertising. The listed brands generally have the same features -

emphasizing environmental friendliness and the hypoallergenic material used [6, 7]. The Zizi_zay_ brand is attractive to users due to the saturation of the assortment and affordable price and takes a decent place among the respondents' answers.

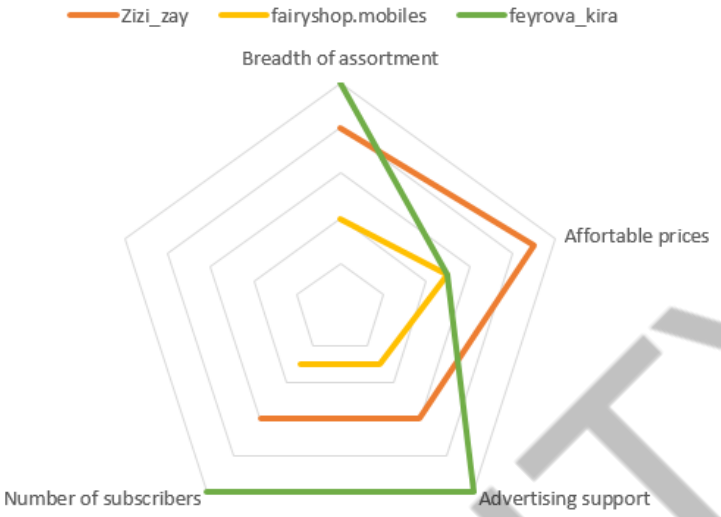

Fig. 2.3 The polygon of the competitive environment of the Zizi_zay_ brand
Source: built by the authors according to [5]

Applying the concept of integrated marketing, it is advisable to consider a 3-level product model [5]. The largest share of the sales volume of products of the Zizi_zay_ brand is made up of hanging toys for the crib, so it is suggested to consider three levels of this particular product (Table 2.2).

Products of the Zizi_zay_ brand are at the growth stage of the Product Life Cycle. To strengthen the position on the market and increase the market share, it is necessary to expand the product range, intensify advertising, involve digital communication channels, and develop measures aimed at expanding the brand's popularity on the Internet.

Price. For setting the base price using the strategy of average prices.

Place. Olesya's customers order products individually; therefore, the brand offers a diverse range of products designed for a specific age category. This will expand market segmentation and meet the needs of preschool children. In this case, to analyze customer behavior, it is advisable to use an analytical tool - a sales funnel- to determine potential customers- and to create a portrait of an ideal customer. Based on this data, form a sales strategy, build a targeted advertising campaign, and consider this when setting up targeted advertising in social networks. It depends on what kind of traffic to send, what methods to communicate with customers and where to send warm leads. All this directly affects the sales conversion rate.

The funnel shows the buyer's path from when the product attracted the customer's attention to the process of its purchase [1]. Funnel is the cheapest and fastest method, which is carried out on social network pages, allowing you to evaluate the effectiveness of marketing and sales.

Table 2.2. Three product levels

Product levels	Essence and components
1. Core Benefit	The mobile helps the child learn to focus on toys, follow them, and distinguish shapes and colors.
2. Actual Product	Quality. The mobile is made only from eco-friendly and hypoallergenic felt material, sintepon filler, a wooden base and strong threads. It has its production technology and an original approach to creating toys.
	Packaging. The entire set of the toy is placed in a box made of kraft cardboard on which the logo and the page's name on social networks are printed. Inside the box is a greeting card; the box is specially designed for the size of the mobile phone and its accessories.
	Design. Olesya develops all varieties and appearances. New mobile designs are created 2-3 times a month with the possibility of making corrections: replacing toy parts and color at the customer's request.
	The Zizi_zay_ brand is still relatively young, but it is quite recognizable by its logo and variety of products among consumers and users of the Instagram social network.
3. Augmented Product	For sale. Advance order, customer consultation, and the possibility of the individual order. Personalization of toys, embroidery of name, date of birth and baby's name. The option of placing an order through various messengers.
	After the sale. Receiving the goods by various delivery services at the customer's request within the country and abroad.

Source: compiled by the authors according to [9]

Promotion. The main promotion tool is the presence of a page on a social network. The content of the pages is created with high quality using professional photos. On the page, groups of products are separated by assortment, photos, and videos - reviews, the workflow of order fulfillment in an accelerated format, and the packaging process. It is created to convey to the consumer information about new products, tools for sales promotion, and announcements of discounts and promotions. Targeted and blogger advertising has been used several times. Such a tool as advertising for bloggers requires a professional approach to writing a brief. It is worth noting that low-quality content from a blogger in the form of advertising harms brand perception among consumers and is also an inappropriate use of the budget. However, advertising with bloggers and paid advertising on social pages is quite expensive, although necessary.

Olesya Ivasechko positions herself as a personal brand Zizi_zay_, which evokes in the target audience associations related to the harmonious development of a child, produces an author's, high-quality, safe toy made with love.

III. ANALYSIS OF THE ZIZI_ZAY_ BRAND ACCOUNT

Currently, social networks are one of the effective methods of promoting goods and services and attracting customers. If you promote a brand on social networks, you need to constantly analyze the engagement rate and the dynamics of the growth of subscribers, and collect information about your audience. We will evaluate the personal

brand of Zizi_zay_ in the social network according to the following criteria:

Account analysis. The Zizi_zay_ brand on Instagram is quite fashionable, dating back to 2020 (fig. 3.1.). The subject of the account: handmade toys for children. It contains photos and video materials about the range of products and the process of their creation, packaging, and reviews. On Zizi_zay_'s profile page, a logo is used as an avatar, which will highlight the brand against the background of competitors and increase its recognition [5].

The brand page on the Instagram network is saturated with colors but maintained in one style. This is very important for online profile design to maintain your original and recognizable style.

Today, the audience of Zizi_zay_'s brand has more than 900 followers. The largest percentage of followers are Ukrainians - 91%, as well as representatives from other countries: Great Britain (2.1%), the Czech Republic (1.3%), and Italy (0.8%).

Content - analysis. Most of the content meets the requirements of the social network. The brand publishes short stories with popular mass hashtags (#mobile, #toys, #giftsforbabies, #pregnancy, #busyboard), which it complements with high-quality photos and video materials, organize contests, and interestingly and creatively support the interests of the target audience.

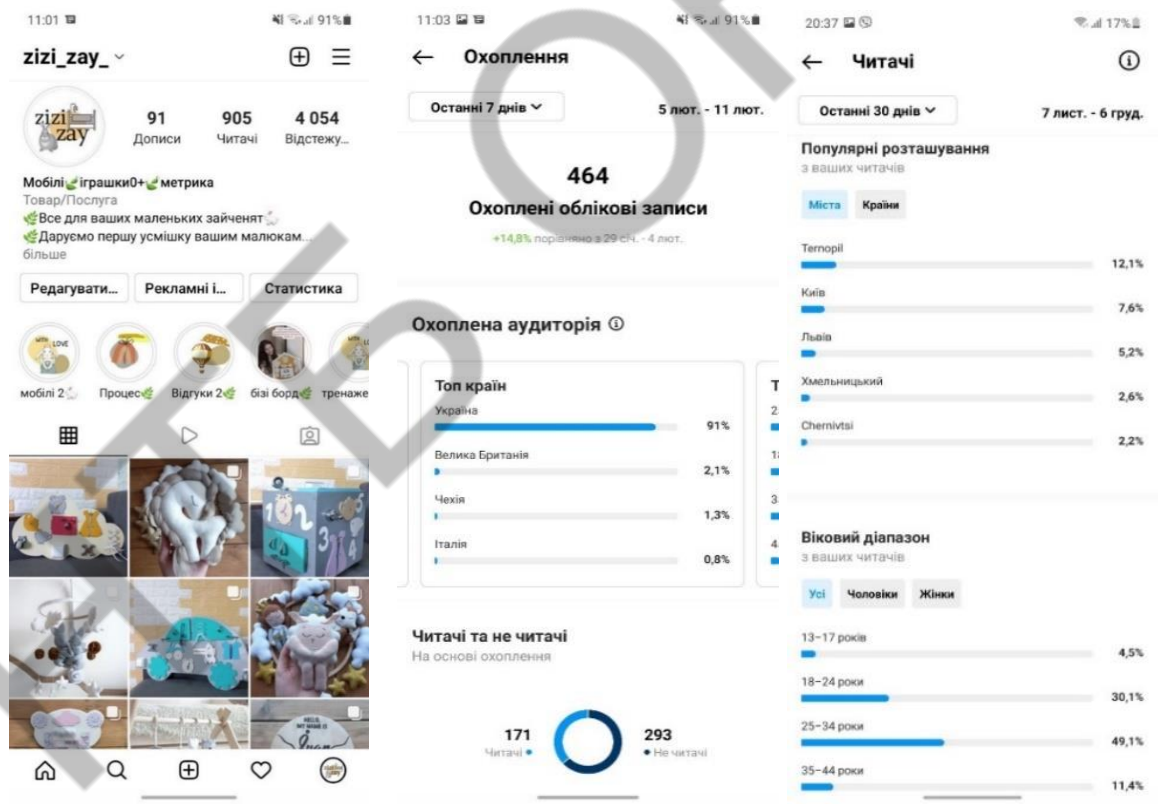

Fig. 3.1. Profile cap and visual. Portrait of the target audience.
Source: [5]

Marketing effectiveness is at the average level, so it is advisable to conduct a statistical analysis of hashtags and evaluate their effectiveness. The hashtag #pregnancy received the largest number of comments, and hashtag #toys were used more often than others (fig. 3.2.). So, hashtags are a simple and affordable way of free promotion that allows you to increase the audience reach rate.

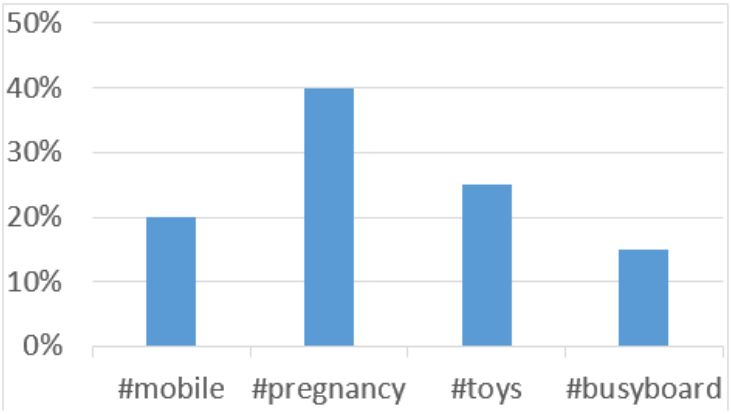

Fig. 3.2. Rating of the most popular hashtags
Source: built by the authors according to [5]

Analysis of communication with subscribers. The Zizi_zay_ brand has enough active communication with subscribers. Posts on the page appear 3-4 times a week and collect an average of 35 likes, and videos at the same time - 260 views. Audience activity can be seen in comments, story views, and message requests. The engagement rate is 3.71%.

Analysis of personal brand promotion. The Zizi_zay_ brand periodically advertises its account, while using targeted advertising, and promotes its page through mutual advertising with other bloggers.

To promote the Instagram account at the beginning of the business, the brand used targeted advertising, but it turned out to be ineffective and did not help to increase the target audience.

Olesya decided to periodically use barter advertising from bloggers to promote her page. This type of advertising turned out to be effective because bloggers have their target audience that trusts the recommendations of this person, there are common interests, and also an honest review of the product, because, before advertising, the blogger reviews the product, and then shows it to his followers. After two barter ads, the result turned out to be insignificant, because the profile was not yet ready, namely, there were no high-quality photos and interesting posts that attract the attention of buyers, and the assortment was not distributed among the saved stories. However, despite this, the first orders arrived. After buying a toy, people wrote down reviews and posted them in the story on my page, which contributed to the increase in sales. To increase the activity of the page, I decided to repeat the barter advertisement once again from 13.12.2021 - 09.01.2022. The result was simply impressive, namely a 100 increase in the number of subscribers and 70 saved under the post. You can analyze how the conversion rate has changed with the help of a sales funnel (fig. 3.3.).

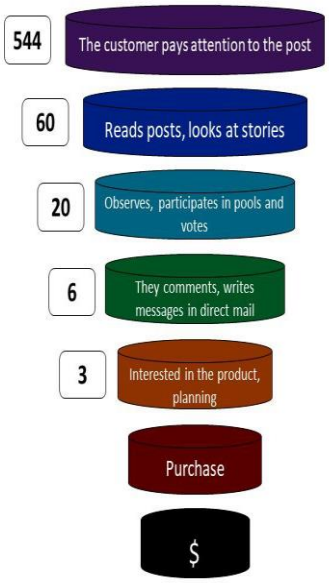

Fig. 3.3. Sales funnel before blogger advertising
Source: compiled by the authors according to [5]

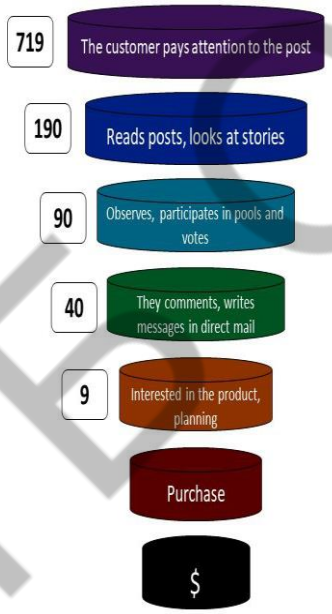

Fig. 3.4. Sales funnel after blogger advertising
Source: compiled by the authors according to [5]

With the help of the conducted analysis, it is possible to find out at which stages of the client's preparation for the purchase, a significant part of the target audience is screened out and, accordingly, make operational decisions to reduce the percentage of rejections. At the first stage of advertising, the conversion was 11% (60/544*100), and after advertising - 26% (190/719*100). The overall funnel conversion was 0.55% (3/544*100) and 1.25% (9/719*100), respectively. Thanks to barter advertising, the conversion rate increased by 2.3 times.

The NPS index (Net Promoter Score) is one of the indicators that shows

customer loyalty. This method was developed by Fred Reichheld in 2003 (tab. 3.1). The essence of the method is to answer only one question. How likely is it that you will recommend Zizi_zay_ brand products to your friends and acquaintances?

Table 3.1. Survey scale

I will not recommend									**Recommend**	
0	1	2	3	4	5	6	7	8	9	10
Critics							Neutral		Promoters	

Source: [10]

After the survey, all respondents are divided into three groups depending on the scores:

loyal customers - ratings of 9-10 points;

neutral buyers - 7-8 points;

critics - 0-6 points.

To study the level of commitment on the Instagram page, a customer survey was conducted, and the sample population for the study period was 100 people. 30 people rated handmade products with 9-10 points, 65 with 7-8 points, and 5 with 0-6 points. Then the customer loyalty index is

$$\text{NPS} = \frac{(promoters - critics)}{total\ number\ of\ respondents} * 100\%$$

$$\text{NPS} = \frac{(30-5)}{100} * 100\% = 25\%$$

The customer loyalty index indicates the potential for growth of the customer base due to their loyalty. It should be noted that customer loyalty is an important factor that affects the recognition and competitiveness of the Zizi_zay_ brand. This indicator can change over time, so periodic monitoring is necessary to respond to changes on time and prevent the loss of customers.

Using the indicator of return on investment in marketing, you can determine the effectiveness of advertising from bloggers using the formula:

$$\text{ROMI}_{\square} = \frac{(income - expenditure)}{expenditure} * 100$$

$$\text{ROMI} = \frac{(6120-2180)}{2180} * 100 = 180\%$$

Income for the studied period was UAH 6,120, and barter advertising expenses were UAH 2,180. Since in this case, the ROMI indicator is more than 100%, the invested investments in marketing made it possible to obtain a profit based on every hryvnia - 1.8 UAH of profit [2, 4].

So, advertising with Insta-bloggers is a great offer for the budget-free promotion of the brand on Instagram.

IV. ZIZI_ZAY_ ACCOUNT ANALYTICS

Key Performance Indicators - KPIs are used to evaluate the effectiveness of brand promotion in social networks. Analytics suggests using different types of metrics:

1) engagement indicators - help to measure the number of users who interact with the company's publications. The virality score helps you understand what kind of content goes viral.

2) reach indicators - the number of unique users who viewed the company's publication. Coverage metrics include the following:

growth outreach - reflects the percentage of people who saw the publication;

audience growth rate - helps track the speed of page growth based on the growth of subscribers.

3) conversion rates – characterizes the benefits the content will bring to the business:

conversion rate - a metric that shows how many people were converted into customers through the page;

CTR (click-through rate) - an indicator that reflects the number of users who responded to a call to action.

Table 3.2. Key Performance Indicators

№	**Indicators**	
1	2	3
1	Engagement rate	
	Post 09/11/2021 $RT_1 = \frac{(45+13+4)}{780} * 100 = 7.94\%$	Post for 12/13/2021 $RT_2 = \frac{(40+14+6)}{880} * 100 = 6.81\%$
2	Average engagement rate	
	For posts for the period from 11/10/2021 to 12/08/2021 $ART_1 = \frac{(261+60+21)/8}{780} * 100 = 5,48$	For posts for the period from 12/13/2021-01/09/2022: $ART_2 = \frac{(314+46+32)/12}{880} * 100 = 3.71$
3	Amplification rate	
	For posts for the period from 11/10/2021 to 12/08/2021 $AR_1 = \frac{21}{780} * 100 = 2,69\%$	For posts for the period from 12/13/2021-01/09/2022: $AR_2 = \frac{32}{880} * 100 = 3.63\%$
4	The level of fidelity	
	For posts for the period from 11/10/2021 to 12/08/2021 $\kappa_1 = \frac{21}{1337} * 100 = 1,57\%$	For posts for the period from 12/13/2021-01/09/2022: $\kappa_2 = \frac{32}{1500} * 100 = 2,13\%$
5	Post outreach	
	For posts for the period from 11/10/2021 to 12/08/2021 $PO_1 = \frac{576}{780} * 100 = 73,84\%$	For posts for the period from 12/13/2021-01/09/2022: $PO_2 = \frac{714}{880} * 100 = 81,13\%$

Continuation of table 3.2

6	Audience growth rate	
	For posts for the period from 11/10/2021 to 12/08/2021 $AGR_1 = \frac{30}{780} * 100 = 3{,}84\%$	For posts for the period from 12/13/2021-01/09/2022: $AGR_2 = \frac{100}{880} * 100 = 11.36\%$
7	Conversion rate	
	Post for 09/18/2021 $CR_1 = \frac{3}{11} * 100 = 27.27\%$	Post for December 13, 2021 $CR_2 = \frac{5}{70} * 100 = 7.14\%$
8	Click-through rate	
	Post for 09/18/2021 $CTR_1 = \frac{11}{840} * 100 = 1.3\%$	Post for December 13, 2021 $CTR_2 = \frac{70}{714} * 100 = 9.8\%$
9	Organic reach	
	For posts for the period from 11/10/2021 to 12/08/2021 $OF_1 = \left(\frac{780}{690} - 1 \right) * 100 = 13.04\%$	For posts for the period from 12/13/2021-01/09/2022: $OF_2 = \left(\frac{880}{780} - 1 \right) * 100 = 12.82\%$
10	Attractiveness level	
	For posts for the period from 11/10/2021 to 12/08/2021 $LR_1 = \frac{30}{780} * 100 = 3.8\%$	For posts for the period from 12/13/2021-01/09/2022: $LR_2 = \frac{42}{880} * 100 = 4.77\%$
11	The level of sociability	
	For posts for the period from 11/10/2021 to 12/08/2021 $TR_1 = \frac{8}{780} * 100 = 1{,}02\%$	For posts for the period from 12/13/2021-01/09/2022: $TR_2 = \frac{10}{880} * 100 = 1{,}13\%$

Source: compiled by the author according to [5]

To evaluate feedback from the audience, such metrics as the level of attractiveness and the level of sociability are used.

Based on the conducted analysis, there is a positive trend in the growth of indicators of marketing effectiveness in social networks: the level of credibility, attractiveness, sociability, clickability, and coverage of the post (tab. 3.2.). The growth rate of the audience for the month has increased by 3 times, which indicates the growing interest of subscribers in this content. The increase in the number of followers is affected by the regularity of publications, so it is advisable to continue to adhere to 3 posts per week.

The engagement rate decreased, but the number of followers increased during this period. The more interesting the content is for users, the higher this indicator will be. However, there is one regularity that is important to know for analytics: namely, as the number of subscribers on the page increases, the engagement rate will decrease.
There is also a decrease in the conversion rate to 7.14% with a simultaneous increase in the number of targeted actions and followers. In general, this indicator is above the normative limit - of 2%.

The click rate increased by 7.5 times, which indicates the effectiveness of the blogger's advertising. Accordingly, the more attractive this offer is, the higher the clickability of the advertisement. It's also a good idea to check how changes in ads will affect CTR and how this will change conversions and sales. Therefore, it is still necessary to analyze the effectiveness of advertising and choose the best option.

For effective promotion of the account, it is necessary to change the strategy, and convert your account into a business account, which will allow you to track not only your statistics through the service but also to check the accounts of competitors and bloggers. You should not use a cheat to increase the number of subscribers because soon there will be a mass unsubscribe, which will negatively affect the reach of the target audience.

V. CONCLUSIONS

The popularity of social networks is growing every year. Social platforms have become not just a place for communication, but also an opportunity to open and promote a business. At the same time, the popularity of the Instagram network, which has become widespread in the field of small business, is growing. Thus, the use of social networks becomes a priority channel of communication between users, promotes the promotion and development of a personal brand, and monetizes the activities of account owners.

In the scientific work, the theoretical and methodological aspects of the formation of a personal brand were studied, the peculiarities of the use of online communications in social networks were considered, and an online survey was conducted to study the opinion of respondents regarding the promotion of the brand in social networks.

The Zizi_zay_ Instagram brand was created in 2020 and has over 900 followers. The visual content is mostly photos and videos about the product in the style of hand-made, their creation technologies, and stylized highlights with different headings.

Based on the studied materials and conducted office and field research, the image of a personal brand was formed, and its visual and verbal components were created: a logo, a mission, and a slogan, which are used as one the tools of brand promotion.

As part of the conducted research, an analysis of the effectiveness of marketing in the social network was carried out using the sales funnel and key performance indicators: attraction, reach, and conversion.

During the research, it was found that the main communications for promoting the brand are the social network Instagram and messengers: Facebook Messenger, Viber, and WhatsApp. Active use of them will allow you to declare yourself to a large audience and form your positioning on the market.

To promote a personal brand and build an algorithm for its promotion in social networks, depending on the business goal, 2 scenarios have been developed that can be used in the process of strategic positioning.

Scenario 1. Increase the reach and number of targeted actions on the page in the Facebook and Instagram networks.

The goal of a marketing campaign is to increase brand recognition and expand its target audience. To achieve the goal, it is necessary to promote the account to a

certain number of followers (for example, 2000 subscribers), increase the number of views of stories (for example, 1000 subscribers), or increase the number of profile views per week. However, with the growing popularity of the brand, it is planned to receive a greater flow of orders and sales in general, to increase its income and profit. After the formed tasks, it is necessary to segment the potential audience, describe the target audience, and build a new communication process.

They can promote products on Instagram with the help of beautiful visual content. First of all, network users perceive information emotionally. Emotions will be the main trigger that will push them to buy. For successful implementation, it is necessary to involve the following tools:

- create a Facebook page, design it, and duplicate Instagram;
- visually fill and maintain an account according to a competently prepared content plan;
- use targeted advertising and advertising from bloggers;
- evaluate the effectiveness of hashtags;
- organize contests, because thanks to posts in the comments, the number of views increases;
- evaluate the effectiveness of the marketing campaign.

Scenario 2. Increased sales and increased brand recognition.

The goal is to increase sales and profits. To do this, it is necessary to scale the business, transfer your account to a business account, create offline and online stores, and automate sales. For segmentation in this scenario, it is advisable to use your customer base in the Facebook and Instagram advertising cabinet to attract look-alike buyers, that is, to attract friends and familiar customers.

Advertising in social networks, cross-promotion, contests, giveaways, bonuses, and promotional codes are the techniques that influence and stimulate the purchase process.

To evaluate the effectiveness of advertising, it is advisable to conduct split testing (A/B testing). With the help of this method, you can understand how the audience reacts to various options for the layout and design of the page, call to action, price, and other business offers. The assessment is carried out using CTR clickability parameters, CPC cost per click, and CPA price per target action. This will help increase sales and customer loyalty to the brand, improve site usability and attract new customers.

Any business is creative. Everyone can turn a hobby into a source of income. This business can be easily scaled in the future.

Today, social networks have become an accessible platform for online sales. You can earn money, help volunteers, and donate to the Armed Forces of Ukraine. It's cool that you can help the country in a difficult time. That is, to make a small contribution to a big victory.

So, the given recommendations are effective and promising, so the Zizi_zay_ brand can implement them in practice.

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THE IMPACT OF THE IMPLEMENTATION OF PROGRESSIVE TAXATION ON INCOME INEQUALITY IN UKRAINE

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Abstract. *The implementation of progressive taxation has been a topic of discussion in many countries, including Ukraine. The main objective of progressive taxation is to reduce income inequality by levying higher tax rates on those with higher incomes. In Ukraine, the implementation of progressive taxation has been viewed as a way to address the issue of income inequality and provide funding for public goods and services. This study aims to evaluate the impact of the implementation of a progressive personal income tax rate in Ukraine designed on the base of Switzerland's personal income taxation experience. The study will use a combination of qualitative and quantitative methods, including surveys, interviews, and secondary data analysis. The results of the study will provide insights into the effectiveness of progressive taxation in reducing income inequality in Ukraine, as well as its potential challenges and limitations. The findings of this study will be of interest to policymakers, economists, and tax experts in Ukraine and other countries considering the implementation of progressive taxation.*

Keywords*: income inequality, progressive taxation, personal income tax, flat taxation.*

I. INTRODUCTION

In recent years, the problem of income inequality has become a serious problem in many countries, including Ukraine. The unequal distribution of wealth and income has led to a growing sense of dissatisfaction and dissatisfaction among many citizens and has contributed to a decline in trust in state institutions. To address this problem, many countries have introduced progressive taxation, under which higher tax rates are levied on individuals with higher incomes. The main purpose of progressive taxation is to reduce income inequality by shifting resources from the wealthy to the less wealthy thereby increasing the demand for goods and servants.

The introduction of progressive taxation in Ukraine has been the subject of much debate, with many arguing that income inequality needs to be addressed and public goods and services need to be funded. Despite this, there is no empirical evidence of the impact of progressive taxation on income inequality in Ukraine. This research work aims to fill this gap by assessing the impact of the introduction of a progressive tax rate on personal income in Ukraine, based on the experience of Switzerland, on income inequality in Ukraine. Switzerland's progressive tax system was chosen as a basis because of its several key features:

1) Fairness: The system ensures that people with higher incomes pay a larger share of their income in taxes, while those with lower incomes pay a smaller share.

2) Economic stability: The system provides a stable source of government revenue and supports the Swiss economy while encouraging investment and economic growth.
3) Political stability: The system has broad public support and has helped to maintain social peace and stability in the country.
4) International competitiveness: The system is flexible, efficient, and supportive of foreign investment, making Switzerland an attractive place to do business.
5) Low tax burden: Despite its progressive tax system, Switzerland has one of the lowest tax burdens among developed countries, contributing to its reputation as a business-friendly country.
6) Simple and transparent: The system is straightforward and easy to understand, with clearly defined tax brackets and rules.

These factors, combined with a strong tradition of political and economic stability, have made Switzerland's progressive tax system a model for other countries to emulate.

The study will use a combination of qualitative and quantitative methods, including surveys, interviews, and secondary data analysis, to assess the effectiveness of a progressive personal income tax rate in reducing income inequality in Ukraine. The results of the study will provide insight into the potential problems and limitations of progressive taxation, as well as its impact on the distribution of income and wealth in Ukraine.

II. LITERATURE ANALYSIS

Taking into account the purpose of the study, consider the arguments of scientists in favor of progressive taxation.

Even the representatives of Marxism - K. Marx [2] and F. Engels [3], who were somewhat skeptical of the tax as a tool of state regulation of income (considering it a burden for all workers), still preferred direct taxes and progressive taxation.

Pavlo Lupyshko (2020) [7] analyzed the experience of foreign countries in the field of taxation of citizens' incomes and concluded that the Personal Income Tax plays an important role in solving social problems of society. Fair taxation of individuals becomes an effective way to solve many social problems, such as guarantees of a decent standard of living for the entire population, social support for all those who need it, and the achievement of social justice.

In general, the redistributive possibilities of the income tax and its progressivity are functionally related. The higher the degree of income tax progression, the greater should be the opportunities for income redistribution from the most well-off to the least well-off, which is aimed at preventing excessive inequality in society and reducing the scale of poverty. However, income tax progressivity, as noted in the financial literature, is a complex concept and is determined by four main factors (determinants of progressiveness), namely choice of tax unit, sources of income subject to tax, tax allowances, and credits, and the tax schedule. [10, p.130-131].

One of the main advantages of progressive taxation is its ability to reduce income inequality. According to a study by economist Emmanuel Saez (2010) [21], progressive taxation helps to transfer resources from the wealthy to the less well-off, addressing the issue of income inequality, which has become a major concern in many countries.

Another advantage of progressive taxation is that it provides a stable source of funding for public goods and services such as education, healthcare, and infrastructure (OECD, 2017 [22]). This can help to improve the standard of living for all citizens and contribute to the overall well-being of society.

Progressive taxation can also increase government revenues, as those with higher incomes are taxed at higher rates (Atkeson & Kehoe, 2007 [23]). This can help to address budget constraints and provide funding for public goods and services. Additionally, progressive taxation is seen as a fairer system of taxation, as those with higher incomes are taxed at higher rates (Kopczuk & Saez, 2004 [24]). This can help to address the issue of tax fairness and encourage all citizens to contribute their fair share. Moreover, progressive taxation can support economic growth by providing funding for public goods and services that are essential for economic development (Piketty, 2014). This can create a more favorable environment for investment and encourage economic growth.

Swiss economist J.-C.-L. Simonde de Sismondi [1, p. 191-192] came to the conclusion about the need to strengthen the economic role of the state to improve people's lives with the help of progressive taxation. “Inasmuch as most of the public expenses are destined to protect the rich against the poor, it is just "that the rich contribute not only in proportion to their wealth but something in addition, in order to maintain this order which is so advantageous to them”.

Economic theories began to actively develop in this direction, pointing to the importance of state intervention in the regulation of income redistribution processes. A kind of pioneer was the English economist J. M. Keynes [4], who focused attention on the idea of "effective demand" and defined taxes and loans as the main source of financing public expenditures. He believed that in order to reduce property inequality in society, it is necessary to increase the incomes of low-income sections of the population through income redistribution. That is why state regulation of income according to Keynes includes progressive taxation and redistribution of income in favor of the poorest sections of the population. R. Musgrave [5] took a similar position regarding tax progressivity as a fair method of taxation and considered it impossible to reduce inequality by applying a proportional tax rate.

Starovoit L. L. [6] concluded that the study of economic theories and concepts of state regulation of incomes revealed that taxes are an effective tool for implementing the state policy of income redistribution. In addition, they are effective and flexible in application, because they are able to influence the regulation of the level of income at all stages of its revenue and expenditure, and the use of benefits as an indirect method of income redistribution helps to make the distribution more equitable.

Pavlo Lupyshko (2020) presented research that provides evidence that the reduction of personal income tax revenues from the incomes of citizens with low incomes and the simultaneous growth of personal income tax revenues from the excess

income of citizens will help to some extent achieve the ratio of social justice and fiscal efficiency of taxation of individuals. And as a result of the increase in the available income of the least well-off population, consumption, and savings will increase, which, in turn, will contribute to the economic growth of the country as a whole.

The study of income and wealth inequality and tax instruments for its reduction is the subject of recent research by A. Sokolovska, Doctor of Economic Sciences [8], in the conclusion of which the author identifies social transfers and taxes as the main instruments for reducing inequality, and the progressive tax as the most effective tax instrument of income redistribution, which does not hinder economic growth.

Raynova Larisa [9] concluded that the reduction of income inequality can also be promoted by the introduction of elements of progression in the taxation of certain types of passive income of individuals, which are in line with the OECD recommendation designed to mitigate the problem of inequality and poverty and support inclusive growth: of a non-taxable minimum income for bank deposits that will reduce the tax burden on small savings, and differentiate rates depending on the value of inherited or donated property.

After analyzing the foreign experience, Pavlo Lupyshko (2020) found that in many countries taxation occurs on a progressive scale. At the same time, in countries with higher tax rates, a high standard of living for the population is ensured, as the funds coming to the budget are directed to the financing of the social sphere. The state must build such a system of distribution relations, in which economic growth would be accompanied by an increase in the welfare of the majority of the population of our country.

Progressive taxation, where those with higher incomes pay a larger portion of their income in taxes, has been a topic of much debate. While it has been proposed as a way to reduce income inequality and provide funding for public goods and services, there are also several disadvantages that must be considered.

One disadvantage of progressive taxation is that it can disincentivize hard work and investment. A study by the Heritage Foundation (2009) [12] found that high tax rates can reduce the incentive for individuals to work, save, and invest, leading to lower economic growth and reduced job creation. Similarly, a report by the Joint Economic Committee (2010) [13] found that high tax rates can make it less attractive for entrepreneurs and investors to take risks and start new businesses.

Another disadvantage of progressive taxation is its complexity. The implementation of a progressive tax system often requires a sophisticated tax system, as well as large amounts of resources to administer. A report by the Tax Foundation (2011) [14] found that the complexity of the tax code can result in significant compliance costs for individuals and businesses, as well as reduced efficiency in the tax system.

In addition to these issues, progressive taxation can also be seen as unfair by those who pay higher tax rates. A study by the American Enterprise Institute (2012) [15] found that many high-income earners view progressive taxation as a form of punishment for their success and that this can lead to reduced public support for the tax system.

Moreover, progressive taxation can also make a country less competitive in the global economy. A report by the CATO Institute (2013) [16] found that high tax rates can deter investment, leading to reduced economic growth and job creation. Additionally, the report found that high-income earners may be more likely to move their income to lower tax jurisdictions, resulting in fluctuations in tax revenue.

Furthermore, progressive taxation can lead to a decrease in tax revenue, particularly if high-income earners find ways to reduce their tax liabilities. For example, a study by the National Bureau of Economic Research (2014) [17] found that high-income individuals are more likely to engage in tax planning strategies, such as deferring income or shifting assets to lower tax jurisdictions. This can result in a reduction in tax revenue and make it harder for governments to fund important public goods and services.

Another disadvantage of progressive taxation is that it can create political instability, as those who pay higher tax rates may push for tax reductions or tax reforms. A study by the Brookings Institution (2015) [18] found that high-tax countries are more likely to experience political turmoil, as citizens may demand lower tax rates or more tax reforms in response to high tax burdens. This can result in significant changes to the tax system, leading to uncertainty and instability.

Finally, progressive taxation can also create a sense of resentment and division within society, as those who pay higher tax rates may feel that they are being unfairly singled out. A study by the Organization for Economic Cooperation and Development (2016) [19] found that high-tax countries are more likely to experience social tensions, as citizens may feel that they are being taxed unfairly or that they are not getting value for their tax dollars. This can lead to reduced public support for the tax system and create political challenges for policymakers.

In conclusion, progressive taxation has several disadvantages, including disincentives to hard work and investment, complexity, perceived unfairness, reduced competitiveness, decreased tax revenue, political instability, and social tensions. These factors must be considered when deciding on the best tax system for a country, and policymakers must find ways to balance the goals of reducing income inequality and funding public goods and services with the realities of the tax system.

Optimization according to the criterion of efficiency consists in minimizing the excess tax burden, while optimization according to the opposite criterion of fairness involves meeting the requirements of horizontal and vertical equality. If the optimization of taxation took place only according to the criterion of efficiency, then to the greatest extent optimal taxation would correspond to a proportional tax on the incomes of citizens. The question of whether a proportional or a progressive tax meets the criterion of justice to a greater extent is debatable in the financial literature due to the significant difference of opinion on ways to ensure vertical equality in taxation.

In any case, Candidate of Economic Sciences Raynova L. B. [9] mentioned that the implementation of this principle involves reasonable differentiation in the taxation of incomes of persons who have different opportunities to pay taxes. However, first of all, the choice between a proportional or progressive tax on the income of citizens from the standpoint of social justice is determined by what inequality in the distribution of

income is permissible in a particular society and what degree of redistribution of income it considers to be fair.

Therefore, the improvement of the personal income tax should be based on a comprehensive approach that combines both the interests of the state in increasing budget revenues and the interests of businesses and individuals in increasing personal incomes and ensuring a growing level of consumption.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The *object* of the research is a personal income tax.

The *subject* of the research is the impact of a progressive personal income tax on the income inequality in Ukraine. The study will focus on the modeling of a progressive tax rates based on Switzerland's tax schedule and a correlation between progressive taxation and income inequality in Ukraine. The research will include an analysis of relevant data and information to evaluate the effectiveness of the progressive taxation system in reducing income inequality in the country.

There are several *methods* that will be used to research the impact of the implementation of progressive taxation on income inequality in Ukraine:

- Secondary data analysis: This involves analyzing existing data and studies related to the topic. Data sources include government reports, academic journals, dissertation works, and news articles.
- Econometric analysis: This involves using statistical techniques to analyze the relationship between progressive taxation and income inequality, especially the Gini coefficient. Data sources include tax records, income data, and other relevant data.
- Comparative analysis: This involves comparing the relevant flat rate at 18% of Ukraine with modeling progressive tax rates, to identify similarities and differences and to assess the impact on income inequality.
- Case studies: Case studies will be used to examine the experiences of Switzerland that have implemented progressive taxation, with a focus on the impact on income inequality.

IV. RESULTS

2.1. Progressive income tax schedule

The federal tax rate on income in Switzerland is a progressive tax, meaning that the tax rate increases as income increases. The tax rate is determined based on the individual's taxable income and wealth. The federal tax rate on income in Switzerland is calculated based on a series of tax brackets, with each bracket taxed at a different rate.

Speaking in more detail, Switzerland's progressive income tax schedule, it is based on the following general principles:

- Taxable income is divided into several brackets and each bracket is taxed at a different rate.
- Taxable income that falls within a bracket is taxed at the corresponding rate, while income that exceeds a bracket is taxed at the next highest rate.

Table 1. Personal income tax rates of the direct federal tax rate on income in Switzerland (for single taxpayers) for 2023

Taxable income (CHF*)		**Rate (%)**
Over	**Not over**	
0,00	14 800,00	-
14 801,00	32 200,00	0,77
32 201,00	42 200,00	0,88
42 201,00	56 200,00	2,64
56 201,00	73 900,00	2,97
73 901,00	79 200,00	5,94
79 201,00	105 500,00	6,60
105 501,00	137 200,00	8,80
137 201,00	179 400,00	11,00
179 401,00	769 700,00	11,20
769 701,00		11,50

* For taxable income above CHF 769 700 the overall tax rate will be 11.5%.

In order to transfer a series of tax brackets of Switzerland into Ukraine, such actions were done:

1) Researched that the amount of minimum wage in Ukraine at the end of 2022 was 6700 UAH [29]
2) Researched that the amount of minimum wage in Switzerland at the end of 2022 was 4030,40 CHF or 159457,13 UAH (the NBU exchange rate was 39,5636 UAH per 1 CHF, dated 31.12.2022) [28, 30]
3) Calculated the minimum wage in Switzerland was 23,8 times larger than the minimum wage in Ukraine.
4) The ratio of Ukrainian and Swiss minimum wages was found, namely the series of tax brackets should be multiplied by 0,042.
5) Finally, each series of tax brackets in Switzerland were multiplied by 0,042 and by 39,5636 (the NBU exchange rate per 1 CHF, dated 31.12.2022).

Table 2. Series of tax brackets of Personal income tax rates in Ukraine (for single taxpayers)

Taxable income (UAH*)		**Rate (%)**
Over	**Not over**	
0,00	24 603,02	0
24 604,02	53 528,19	0,77
53 529,19	70 151,85	0,88
70 152,85	93 424,97	2,64
93 425,97	122 848,85	2,97
122 849,85	131 659,39	5,94
131 660,39	175 379,61	6,60
175 380,61	228 076,62	8,80
228 077,62	298 228,46	11,00
298 229,46	1 279 523,12	11,20
1 279 524,12		11,50

* For taxable income above 1 279 524,12 UAH the overall tax rate will be 11.5%.

2.1. Comparative analysis using the Gini coefficient

In order to compare under which type of tax income inequality will be less, Gini coefficients for both flat and progressive taxation were calculated.

The Gini coefficient, also known as the Gini index, is the statistical measure used to measure the income distribution among the country's population, i.e., it helps measure the income inequality of the country's population.

It is a value between 0 and 1. A higher number indicates a greater degree of income inequality. A value of 1 indicates the highest degree of income inequality, where a single individual earns the country's entire income. A value of 0 indicates that all individuals have the same income. Thus, a value of 0 indicates perfect income equality. One of the Gini index's limitations is that it requires that no one has negative net wealth.

In order to calculate the Gini coefficient, the following actions were taken: based on Table 3, it was assumed that each person per year earns at the figure that is the lowest limit in each distribution These numbers were then grouped according to the progressive tax scale that was constructed earlier.

Table 3. Distribution of the population by average per capita equivalent total income

Distribution of the population (%)	**Distribution of the population (%) by average per capita equivalent total income per year, UAH**
4,5	below 60000
17,7	60000-84000
27	84000-156000
24,3	156000-276000
8,5	276000-324000
18	over 324000

** Compiled by the author based on [26]*

In order to calculate which share of the population receives which share of income, the population size as of 12/31/2021 [27] was taken and multiplied by the corresponding percentages by a group.

Table 4. Figures for calculating the Gini coefficient based on the flat taxation

Population, people	**Share of population, %**	**Pre-tax income, million UAH***	**PIT rate, %**	**After-tax income, million UAH**	**Share of income, %**
1852529	4,50	0,00	18	0,00	0,00
11115171	27,0	933674,36	18	765612,98	14,82
7286612	17,70	437196,73	18	358501,32	6,94
10003654	24,30	1560570,01	18	1279667,41	24,78
7410114	18,00	2400876,94	18	1968719,09	38,12
3499221	8,50	965784,86	18	791943,58	15,33

* Pre-tax income per year

Table 5. Figures for calculating the Gini coefficient based on the progressive taxation

Population	Share of population, %	Pre-tax Income, million UAH	PIT rate, %	After-tax income, million UAH	Share of income, %
1852529	4,5	0,00	0	0,00	0,00
11115171	27	933674,36	0,77	926485,07	15,16
7286612	17,7	437196,73	0,88	433349,39	7,09
10003654	24,3	1560570,01	2,64	1519370,96	24,86
7410114	18	2400876,94	2,97	2329570,89	38,12
3499221	8,5	965784,86	6,60	902043,06	14,76

* Pre-tax income per year

It is important to note that all the rows were organized from the poorest to the richest. For instance, it was calculated that the bottom 8,5% of the population earns 15,3% of income, 17,7% of the population earns 6,9% of income, 24,3% of the population earns 24,8% of income, and 27% of the population earns 14,8% of income, etc.

Next, the first row from the '% of Population that is richer' column was filled. Then, all the figures were added (from 0,069 to 0,381), the rows in 'Fraction of population' below it. Hence, we get 0.955. After that, to fill the second row in the '% of Population that is richer' column, figures from the third to last rows were summed up. All the next rows were calculated in the same algorithm.

In order to fill the 'Score' column, the following formula was used:

$$Score = Fraction\ of\ Income * (Fraction\ of\ Population + 2 * \%\ of\ Population\ that\ is\ richer).$$

For instance, the score for the 2nd row is 0,069*(0,177+2*0,778) = 0,120; the score for the 3rd row is 0,148*(0,27+2*0,508) = 0,191 and so on. After that, all the terms in the 'Score' column were added.

Finally, for calculating the Gini coefficient, such formula was used:

$$Gini = 1 - Sum$$

So, for a flat tax rate of 18% Gini coefficient is 0,328 (1 - 0,672).

Table 6. Figures for calculating the Gini coefficient based on the flat taxation

Fraction of population	Fraction of income	% of the population that richer	Score
0,045	0,000	0,955	0,000
0,177	0,069	0,778	0,120
0,270	0,148	0,508	0,191
0,085	0,153	0,423	0,143
0,243	0,248	0,180	0,149
0,180	0,381	0	0,069
1	1	**Sum**	0,672

As with the previous type of tax rate, all the rows were organized from the poorest to the richest. For instance, it was calculated that the bottom 8,5% of the population earns 14,8% of income, 18% of the population earns 38,1% of income, 24,3% of the population earns 24,9% of income, and 27% of the population earns 15,2% of income, etc.

Next, the first row from the '% of Population that is richer' column was filled. Then, all the figures were added (from 0,071 to 0,381), the rows in 'Fraction of population' below it. Hence, we get 0.955. After that, to fill the second row in the '% of Population that is richer' column, figures from the third to last rows were summed up. All the next rows were calculated in the same algorithm.

In order to fill the 'Score' column, the following formula was used:

$$Score = Fraction\ of\ Income * (Fraction\ of\ Population + 2 * \%\ of\ Population\ that\ is\ richer).$$

For instance, the score for the 2nd row is 0,071*(0,177+2*0,778) = 0,123; the score for the 3rd row is 0,148*(0,085+2*0,693) = 0,217 and so on. After that, all the terms in the 'Score' column were added.

Finally, for calculating the Gini coefficient, such formula was used:

$$Gini = 1 - Sum$$

So, for a progressive tax schedule that was built earlier, the Gini coefficient is 0,272 (1 - 0,728).

Table 7. Figures for calculating the Gini coefficient based on the progressive taxation

Fraction of population	**Fraction of income**	**% of the population that richer**	**Score**
0,045	0,000	0,955	0,000
0,177	0,071	0,778	0,123
0,085	0,148	0,693	0,217
0,270	0,152	0,423	0,169
0,243	0,249	0,180	0,150
0,180	0,381	0	0,069
1	1	**Sum**	0,728

To sum up, the Gini coefficient at progressive taxation is 0,272, and at flat taxation is 0,328. Since the smaller the coefficient, the smaller the income inequality, it can be argued that income inequality will be smaller with a progressive personal income tax rate. In other words, if such a system with progressive personal income tax rates based on Switzerland's progressive tax schedule is implemented in Ukraine, it will help to reduce income inequality.

V. CONCLUSIONS

In conclusion, the research has aimed to evaluate the impact of the implementation of progressive taxation on income inequality in Ukraine. Through a thorough analysis of available data and literature, the study found that progressive taxation has the potential to effectively address income inequality in Ukraine, if properly implemented and accompanied by complementary policies and reforms. Nevertheless, it is also important to note that some challenges, such as tax evasion, corruption, and limited administrative capacity, need to be addressed for the progressive taxation system to achieve its intended goals.

It is recommended that the Ukrainian government continues to monitor and evaluate the implementation of progressive taxation and make adjustments as needed, while also investing in strengthening its tax administration and addressing the root causes of income inequality in the country. Overall, the research highlights the importance of progressive taxation in reducing income inequality and contributing to more equitable and sustainable economic growth.

Of course, the introduction of a progressive scale containing rates significantly lower than the current tax rate requires an analysis of changes in its fiscal role. In this direction, we will continue our research on this topic.

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FORMATION OF STRATEGIC MANAGEMENT TOOLS AT PJSC «OKZ»

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Abstract. *Globalization processes encourage in-depth study of such an important point in the management of a modern enterprise as the management of the strategic development of the enterprise. That is why it is important to solve the issues related to ensuring the processes of managing the strategic development of the enterprise, the solution of which will allow enterprises to ensure effective management of the strategic development of the enterprise, which determines the relevance of the research topic.*

Chapter II «Theoretical foundations of strategic enterprise management» examines approaches to the concept of «strategic management», methods and tools. Chapter III «Analysis of the internal and external environment of cognac production enterprises» examines the market of cognac products, competitors and the activities of PJSC «OKZ». Chapter IV «Development of the main tools of strategic management of the company producing brandy products on the example of PJSC «OKZ»», the tools were formed and the feasibility of improving the strategic management system was substantiated.

Keywords: *enterprises, market, cognac, tools, strategy, development, investment costs.*

I. INTRODUCTION

Relevance of the research's chosen topic. The modern conditions of the development of enterprises are characterized by high uncertainty of the external environment due to the full-scale war of the Russian Federation against Ukraine, a rapid change in the purchasing power of consumer demand and fierce competition. Strategic management, strategy and effective management tools are the basis for the survival and development of enterprises in modern conditions, as they allow examining the external and internal environment of the enterprise and implementing timely and effective measures. Therefore, the formation of the main strategic management tools and development measures for Ukrainian enterprises is timely and relevant. Many works of such domestic and foreign scientists as I. Ansoff, M. Porter, O. Vikhanskyi, Z.E. Shershnyova, F. Kotler, M.S. Krochak, L. Oliinyk, A. Kuznetsova, I. Yershova, I. Ageeva, and others, who present different views on the issue of strategy formation and the main strategic tools of management. However, these works do not sufficiently cover the practical aspects of the formation of strategic management tools for the cognac producer, which determined the purpose of the study.

The purpose of the study. The purpose of the work is the process of forming the strategic management toolkit of PJSC «OKZ». To achieve the goal, the following tasks were solved:

– consider conceptual approaches to strategic management and explore the strategic tools of enterprise management;

– analyze the state of development of the macro-environment of cognac production enterprises and the internal environment of PJSC «OKZ»;

– to carry out a study of the strategic management toolkit used by PJSC «Odessa Cognac Factory»;

– to form the main strategic management tools of PJSC «OKZ» in war and post-war times and justify the expediency of measures.

The object of the research is the process of strategic management of the enterprise. **The subject of the study** is the theoretical, methodological and practical aspects of the formation of the strategic tools of enterprise management.

The methodological base of research. The theoretical and methodological basis of the research is scientific research on strategic management, monographs, and scientific articles of domestic and foreign scientists. The work uses both general scientific and special research methods: analysis, synthesis and formalization (to systematize types of strategy, methods and tools of strategic management), forecasting method (to identify trends in the development of the cognac market), systematic approach (to study external and internal environment and development of strategic tools), statistical method (for processing, systematization and generalization of statistical data), graphic (for visual display of research results), PEST and SWOT analysis, etc.

Keywords: enterprises, market, cognac, tools, strategy, development, investment costs.

II. THEORETICAL PRINCIPLES OF STRATEGIC ENTERPRISE MANAGEMENT

2.1. Conceptual foundations of strategic enterprise management

A modern tool for managing the development of enterprises and industries in the conditions of increasing changes in the external environment and related uncertainties is the methodology of strategic management. Strategic management is an activity that ensures the creation and maintenance of strategic correspondence between the goals of the organization, its potential and opportunities in the external environment, which enables the organization to achieve competitive advantages, survive in the long term, while achieving its goals [1]. According to M. Porter, strategy is the creation of a unique and profitable position, which involves a certain set of activities [4]. In order to deepen the understanding of the essence of strategic management, it is considered in the following sections: elementary, as a set of elements, the interaction between which ensures the formation and achievement of goals during the implementation of the organization's development strategy; process, as a cycle of strategy development and implementation aimed at achieving strategic alignment between the organization and the external environment; the methodology of making strategic decisions and methods of their practical implementation [2, 3]. The characteristic features of the enterprise's strategic management system depend on the interaction of the following factors: branch affiliation; enterprise size; type of production, level of specialization, concentration

and cooperation; characteristics of production potential; availability (absence) of scientific and technical potential; the level of management development and personnel qualifications, etc. [1]. The core of strategic management is a system of strategies, which includes a number of interconnected specific business, organizational, and labor strategies. Thus, the essence of strategic management is the formation and implementation of the organization's development strategy based on continuous control and assessment of changes occurring in its activities in order to maintain the ability to survive and function effectively in the conditions of an unstable external environment.

2.2. Strategic tools of enterprise management

The main stages of the strategic management process include: strategic analysis, strategic planning, organization of strategy selection and implementation, strategic control [1]. Methods and tools of strategic management can be conventionally classified depending on their use at different stages of strategic management. Let's consider the strategic tools that have the greatest practical significance and are widely used in Ukrainian enterprises:

1. The goal tree is a graphic representation of the interrelationship and subordination of goals, reflecting the division of missions and goals into goals, sub goals, tasks, and individual actions [5, 6].

2. SWOT analysis is one of the methods of analyzing internal and external factors that affect the work and development of the company. Advantages: ease of conducting and using data; versatility; full overview of the situation; data for further use [5].

3. Competitive analysis – a method of detailed study of the market situation, allows analyzing the business from the competitor's point of view [5]. The process includes 3 stages: identification of competitors, study of their activities and analysis of all components.

4. Boston Consulting Group (BCG) matrix, which considers two factors: relative share and market growth rate [5].

5. McKinsey's matrix – includes nine quadrants and is based on an assessment of the long-term attractiveness of the industry and the competitiveness of a strategic business unit, etc. [5].

Each of the considered tools should be adapted to the specifics of the industry and the enterprise.

The conducted analysis of strategic management tools makes it possible to draw the following conclusions: it has been proven that the classic definition of strategy is its understanding as a general course of action that determines the future development of the enterprise in terms of achieving competitive advantages and success; it was established that in the conditions of a change in the external environment, the enterprise should carry out effective strategic management. At each stage of the process of strategic management of the enterprise, appropriate strategic tools should be used.

III. ANALYSIS OF THE INTERNAL AND EXTERNAL ENVIRONMENT OF ENTERPRISES-PRODUCERS OF BRAND PRODUCTS

3.1. Analysis of the state of development of the macro-environment of enterprises producing cognac products

Among the branches of Ukraine's economy that have prospects for entering the world market, viticulture and wine production, which is represented by such main types of products as wine, champagne, cognac, are included. The consumer properties of these drinks are unique and in demand not only in domestic, but also in foreign markets [7, 8]. The basis of the industry is the total area of land occupied by vineyards all over the world. The data show that for almost 40 years, the area of land devoted to the cultivation of grapes has significantly decreased: only the first 10 years have seen an increase in the indicator, all others – its gradual decrease. The percentage ratio of the world vineyard area between EU countries and countries outside of it in 2019 was almost 50% to 50%, respectively, in 2020 this ratio changed slightly: vineyard areas outside the EU already accounted for 51% of their total figure. The growth of this indicator occurs due to the increase in the area of land under vineyards in Brazil, Chile, New Zealand, the Russian Federation and China [7, 8]. Before the full-scale war of the Russian Federation against Ukraine, the area of vineyards was ≈ 40 thousand hectares. Vineyards are concentrated in Odessa, Kherson, Mykolaiv, Zaporizhzhia and Zakarpattia regions. According to the State Statistics Service of Ukraine, the largest area of vineyards (in the structure of plantations) in the fruit-bearing age is in the Odessa region – more than 27 thousand hectares (64%) [15]. In connection with climatic changes, the geography of viticulture in Ukraine has significantly expanded to the north and covers almost all of Ukraine [8, 9].

The share of domestically produced cognac sales through Ukrainian trade networks is 66.4%, the remaining 33.6% is imported [10]. According to the WHO report, the highest level of alcohol consumption is in southern European countries, where wine is mainly consumed, and the lowest is in the north of Europe, where strong drinks are more often consumed, and beer is widespread in the countries of Central Europe. According to this report, Ukraine is the leader in Europe in terms of the share of hard alcohol consumption - 51.5%, ahead of Estonians - 50.3%, Belarusians - 49.0% and Montenegrins - 44.6% [11, 12]. In 2021, spirits were most consumed in Ukraine (52.3%), followed by beer (36.4%). According to a survey conducted by a sociological group, 68% of surveyed Ukrainians drink alcoholic beverages, 33% drink it less than once a month, 26% - several times a month, 8% - several times a week, 1% - every day [13, 14]. According to the State Statistics Service, in 2021, Ukrainians purchased 3 billion 662 million hryvnias worth of cognac in retail chains. Sales of Ukrainian-made alcohol amounted to UAH 2 billion 431 million, which is 66.4% [10]. According to Pro-Consulting, the share of consumption of domestically produced cognacs in Ukraine is growing (by 20% in 2021). Ukrainians prefer cognac of domestic origin from the inexpensive price segment [15].

One of the main characteristics of the world brandy production is its oligopolization in combination with active manifestations of state control of the quality of goods and their distribution. World leaders Hennessy, Martell, Remy Martin control

70% of the entire world cognac market [21]. Among the most famous manufacturers, the following can be distinguished: Diageo (Great Britain); Pernod Ricard (France), owns the Yerevan Cognac Plant (TM «Ararat») and the Georgian company GWS (TM «Tamada», «Stari Tbilisi»); LVMH (France) TM «Louis Vuitton», «Givenchy», «Kenzo», «Chaumet, Moet & Chandon», «Hennessy», «TAG Heuer». The largest domestic producers of cognacs are: PJSC «OKZ», OP «Uzhgorod Cognac Plant», PJSC «House of Vintage Cognacs «Tavria»» and PJSC «Galicia Distillery2.

PJSC «OKZ» is a leader in the production of cognacs in Ukraine, covering more than 20% of the domestic market. The plant is a full-cycle brandy production enterprise using classic French technology. Produces more than 50 names of vintage and ordinary cognacs, 13 types of champagne. The trademarks include «Shustov», «Desna», «Odessa», «Zoloty Duke», «Arkadia»", «Yuvileyniy2, «Chaika», «Grand France» [18].

OP «Uzhhorod Cognac Factory» is one of the largest producers of domestic cognacs. The plant's share in the domestic cognac market is 13%. Trademarks of vintage cognacs «Uzhhorod», «Tysa», «Karpaty», ordinary cognacs «Zakarpatskyi», «5 stars», «3 stars», «Beskydy» and «Nevytsky Zamok» [19].

PJSC «House of Vintage Cognacs» Tavriya» is one of the largest enterprises in the cognac industry of Ukraine, with a full production cycle. It occupies 15% of the domestic market. The line of cognacs of TM «Tavria» includes ordinary, vintage and collectible cognacs: «Tavria», «Kakhovka», «Tavria Classic», «Ascania», «Kherson» and «Imperial» [20].

PJSC Galicia Distiller produces strong alcoholic beverages; its portfolio includes the brands of cognacs «Greenwich», «Buchach» and «Renuage». Currently, Galicia Distillery has a dynamic production with a share of 10% [21].

3.2. Analysis of the internal environment of PJSC «Odessa Brandy Plant»

PJSC «OKZ» (TM «Shustoff»), founded in 1863 in Odessa by the trade and industrial company «Shustov and Sons», is part of the holding «Global Spirits», which owns a number of vodka production enterprises, tinctures, cognacs and brandy, wines, champagne, vermouths and low-alcohol drinks. In 1900, the company was awarded the Grand Prix at the World Exhibition in Paris, as a result of which the plant's products were honored to be labeled under the definition of «cognac» [18]. The plant is a full-cycle brandy production enterprise using classic French technology. The plant owns significant areas of its own elite vineyards (about 1,000 hectares) [18]. The plant is a producer of more than 50 names of vintage and ordinary cognacs, 13 types of champagne. His trademarks include: «Shustov», «Desna», «Odessa», «Golden Duke», «Arkadia», «Jubilee», «Chaika», «Oreanda», «Grand France» and others. The distillery of the Odessa Cognac Plant is the largest in Europe. During the alcohol smoking season, up to 3 million deciliters of cognac wines can be smoked. About 15,000 barrels in which brandy is aged are in operation at the factory [18]. Three automatic production lines work in the bottling plant, as well as a souvenir line. The production capacity of the lines is 4375 bottles/hour. The first line produces cognac – «Desna», «Chaika», «Arkadia», «Yuvileiny». The second line produces TM «Shustov», «Shokolatye». In 2021, the classic Shustoff line was restyled, the assembly

recipes were updated, and a completely new product was obtained.

The net income of PJSC «OKZ» from the production of cognac in 2020 amounted to UAH 546,456,000, and in 2019, it was UAH 541,227,000, an increase of UAH 5,229,000. The company purchased and put into operation fixed assets with an initial cost of UAH 9,929,000. During the experimental period, the volume of cognac production and sale tends to decrease by 20%. The price policy of PJSC «OKZ» is aimed at the medium and high price segment.

In 2019, the company concluded contracts for the supply of its products to Australia and Poland and is actively developing the US market. In total, the company exports to 14 countries. Export of cognac products from Ukraine has increased significantly over the past two years; supplies are made to the following countries: Azerbaijan, China, Georgia, Israel, Lithuania, Slovakia, and Tajikistan. Also, the company cooperates with the ROZETKA chain of stores, supermarkets «ATB», «Kopiyka», «Silpo», «Tavria V», you can buy «OKZ» products in a special branded store of PJSC «OKZ», and there is also an online store.

3.3 Research of strategic management tools PJSC «OKZ»

In order to increase competitiveness and increase profits, enterprises that form a supply on the cognac market are trying to improve strategic management, which is based on two processes: strategy formation and its implementation. Let's consider the main tools of strategic management at the enterprise. An expert assessment of the change in the external environment factor was carried out on a 5-point scale, the weighted average expert assessment of each individual factor was calculated and table 3.1 was constructed.

Table 3.1

Matrix of the importance of macro factors of PJSC «OKZ»

Factor	Weight	Factor	Weight
Political		**Economic**	
State influence on the industry	0,07	Exchange rate fluctuations	0,03
Cooperation with the EU	0,02	Inflation rate	0,02
Military actions in the state	0,11	An increase in the unemployment rate	0,03
Social		**Technological**	
Distribution of healthy lifestyles	0,04	The level of innovation and technology	0,05
Changing preferences of the population	0,02	The need for innovation	0,04
Lowering the level of education	0,04	Availability of modern technologies	0,06
Environmental		**Law**	
Environmental situation	0,02	Changes in the tax code	0,08
Use of natural resources	0,04	Lack of regulation of competition	0,02
Deterioration of the quality of natural resources	0,07	Instability of legal regulation	0,03

Source: developed by the author based on [23, 24, 25]

From the table 3.1 identified the factors that have the greatest impact on the operation of the enterprise in the long term. In order to study competitiveness, a polygon of competitiveness was built. The analysis was carried out in comparison with the main competitors of the company: OP «Uzhgorod Cognac Plant» (TM

«Zakarpatskyi»), PJSC «House of Vintage Wines «Tavria», TM «Tavria»), PJSC «Galicia Distillery» (TM «Prykarpatskyi») and the enterprise under investigation by PJSC «Odessa Cognac Factory» (TM «Shustov») (Fig. 3.1).

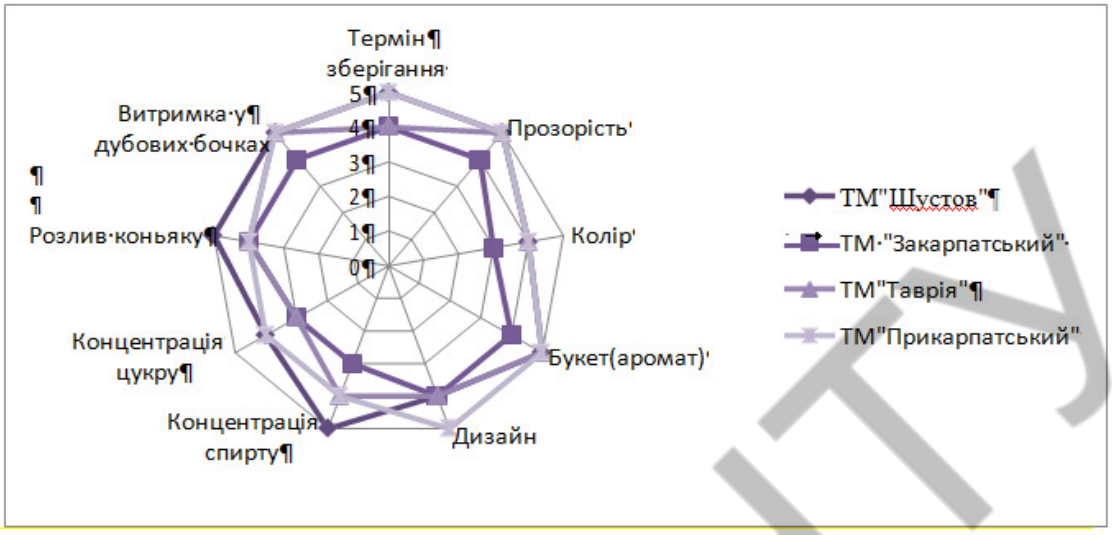

Fig. 3.1. Polygon of the competitiveness of TM «Shustov» products

Source: developed by the author

PJSC «OKZ» realizes various types of alcoholic products, which have an unequal weight in the company's business portfolio. Therefore, when developing a strategy, it is necessary to differentiate these products and consider their role for the enterprise using the BKG and McKinsey matrix. To carry out the portfolio analysis, we have taken the classification according to the following strategic economic zones (SZG): SZG № 1 – ordinary cognacs (aged for 3-5 years); SZH № 2 – vintage cognacs (aged 8-15 years); SZH No. 3 – collection cognacs (aged 15-37 years).

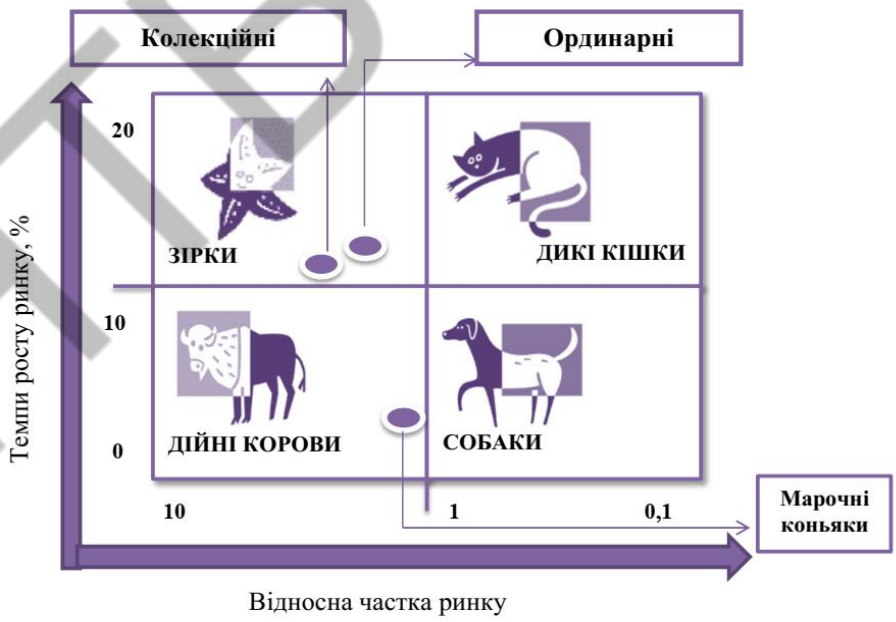

Fig. 3.2 BKG matrix for PJSC «Odessa Brandy Plant»

Source: compiled by the author

According to the results of the construction of the BKG matrix, it can be

concluded that SZH № 1 and SZH № 3 are located in the «Star» zone, which is characterized by high TRR and VCR. This business is rapidly developing, it is necessary to increase investment in it in order to maintain the existing position in the market. In the future, SZH № 3 will grow into the «Milk cows» zone, which will bring stable income. SZH № 2 was located in the «Dairy Cows» zone, which is characterized by medium high HCR and low TTR. This business is profitable, stable and has positive cash flows, which must be directed to the business zones of «Star» for their support. Next, the McKinsey matrix was constructed (Fig. 3.3).

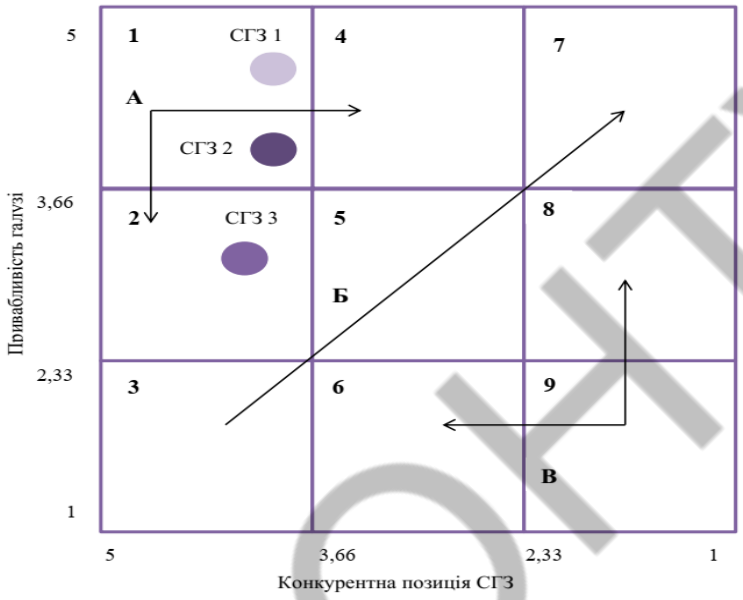

Fig. 3.3 McKinsey matrix for PJSC «OKZ»

Source: developed by the author

So, from fig. 3.3 we see that FZG № 1 and FZG № 2 are located in zone A, (square 1), this means that the company needs to invest in the development of these FZGs and maintain a strong position in the market. It is necessary to focus attention on maintaining competitive advantages and the possibility of expanding production. The high attractiveness of the industry and the average competitive position, characterized by the FTA № 3, in this direction, it is necessary to strengthen the weak positions of the business, determine competitive advantages and take leading positions in the spheres of operation of competitors.

Analysis of the portfolio of PJSC «OKZ» shows that the two business units have stable competitive positions and sufficient shares in the market. Ordinary and vintage cognacs are at the stage of their development, and it is necessary to invest in them to support existing positions, and for collectible cognacs, it is recommended to determine development trends in the market, the possibility of introducing innovations, strengthening marketing activities, improving operational technologies to transfer them from the stage liquidation in the phase of growth and further profitable growth. A SWOT-analysis was developed to identify strengths and weaknesses, opportunities and threats.

SWOT-analysis PJSC «OKZ»

	O – opportunities	**T – threats**
	Simplifying access to the EU market. Reduction of excise taxes. Growing demand for brandy products. Development of production technologies. Implementation of resource-saving technologies.	High competition in the domestic market. Increase in the share of imported products. Changes in consumer preferences due to COVID-19. Full-scale war of the Russian Federation against Ukraine. Reduction of brandy consumers. «Dry law» during the war in most regions of Ukraine.
S – strengths	**S*O**	**S*T**
Extensive experience and market leadership in Ukraine. International popularity of TM. High quality products. Modern technological equipment. Own raw material base. Advantageous geographical location. Availability of elite cognacs. A new brandy distillery shop.	Measures for survival strategy: Preserving market share due to product quality. Introduction of low-price segment production. Organization of cooperation with Ukrainian restaurant chains. Measures for the development strategy: Expansion of the raw material base. Application of ecological mineral fertilizers for processing vineyards. Production of non-alcoholic sparkling wine.	Measures for survival strategy: Increasing the production capacity of primary production. Organization of safe storage of alcohol. Sparkling wine positioning. Measures for the development strategy: Organization of the release of the family brandy collection. Diversification.
W – weak sides	**W*O**	**W*T**
Slow promotion of novelties and lack of advertising in the premium segment. Concentration on the Ukrainian market. Low rates of introduction and development of new original types of products.	Measures for survival strategy: Creation of a new TM «Ukrainian brandy» for entering the foreign market. Measures for the development strategy: Transition to natural cork. Implementation of targeted advertising. Improvement of the line of ordinary cognacs.	Measures for survival strategy: The use of the latest technologies to increase the organic of products. Measures for the development strategy: Opening of stores throughout Ukraine.

Source: compiled by the author

Thus, summarizing the above, the following conclusions can be drawn:

From the analysis of the cognac industry, it can be stated that it is in a state of deterioration. The cognac market is now very saturated and competitive. In such a competitive struggle, only efficiently working Ukrainian companies survive, we are talking about powerful enterprises, such as PJSC «OKZ» which works in a vertically integrated format. The strategic management tools used by PJSC «OKZ» are used to a greater extent during strategic analysis, while other stages of the strategic management process remain almost untouched, so the development of other tools is necessary.

IV. DEVELOPMENT OF STRATEGIC MANAGEMENT TOOLS PJSC «OKZ»

4.1. Formation of the main tools of the strategic management system of PJSC «OKZ»

PJSC «OKZ» lacks universal development of strategic management tools that could be used for different strategies and in different situations. That is why we have developed the strategic toolkit of PJSC «OKZ» taking into account the specifics of the cognac market and the dynamics of our company's development. When determining the strategic directions of the enterprise's development, first of all, it is necessary to pay attention to the development strategies that it implements. For this, a tabular model of combinations of strategies was created, which shows the types of strategies used by PJSC «OKZ» and competing enterprises (Table 4.1).

Table 4.1

A model of combinations of strategies of competing enterprises in the domestic cognac/brand market of Ukraine

Name of Company	Concentration	Integration	Diversification
PJSC «OKZ»	Product development; Market development	Straight vertical; Reverse vertical	Centered; Horizontal
OP «UKZ»	Product development; Market development	Straight vertical; Reverse vertical	Horizontal
PJSC «House of vintage cognacs «Tavria»»	Product development; Market development	Horizontal	Horizontal
PJSC «Galicia Distillery»	Product development; Strengthening positions	Vertical	Centered

Source: improved by the author based on [26]

PJSC «OKZ» carries out vertically integrated growth, that is, control of technological processes from the production of raw materials to the manufacture of finished products. The enterprise, using its well-known brand, can carry out conglomerate diversification by mastering new technologies for the production of new products and entering new markets. The beginning of a full-scale war of the Russian Federation against Ukraine in 2022 requires the enterprise to form measures for a survival strategy, and after its end, to move to measures to support the development strategy. Let's define directions of strategic business development:

1. Measures for survival strategy: introduction of low-price segment production; organization of cooperation with Ukrainian restaurant chains; preservation of market share due to the rhythm and quality of products.

2. Measures for the development strategy: expansion of the raw material base; application of ecological mineral fertilizers for processing vineyards; production of non-alcoholic sparkling wine.

To avoid threats from the external environment, we will use the company's strengths and offer the following measures:

1. Measures for survival strategy: organization of safer storage of alcohol; increase in production capacities of primary production; more sparkling wine

positioning.

2. Measures for the development strategy: organization of the release of a brandy family collection; price positioning of VIP products; expanding the assortment of other positions at the enterprise.

In order to eradicate the weaknesses of the organization at the expense of opportunities, it is possible to use the strategy of improving the company with the help of measures, namely: a measure for the survival strategy: the creation of a new TM «Ukrainian brandy» for entering the foreign market:

1. Measures for the development strategy: transition to natural cork; implementation of targeted advertising; improvement of the line of ordinary cognacs.

To nullify weaknesses and minimize threats from the external environment:

1 Measures for the survival strategy: increase the use of domestic products; use of the latest technologies to increase the organic of products.

2. An event for the development strategy: the opening of branded stores throughout Ukraine.

4.2. Justification of the feasibility of the proposed measures

Our chosen survival and development strategies are appropriate and interrelated with each other. The survival strategy is an anti-crisis, purely defensive strategy, which is used in cases of a certain disorder of the economic activity of the market. The goal of the strategy is to stabilize the situation, that is, to create conditions for a further transition to a growth strategy. The company's development strategy can be characterized as a long-term, flexible action plan of an innovative direction with an appropriate level of risk, which is based on a detailed analysis of the company's internal and external environment, depends on human factors and requires investments to achieve effective results, increase the competitiveness of products and the company. That is why the measures for the implementation of the survival strategy were developed in the conditions of military operations and aimed at preserving the enterprise in difficult realities.

Description and calculations of measures for the development strategy of PJSC «OKZ»

West	Brief description of the event	Justification
Transition to natural cork	Using natural cork for bottle caps is really important. After all, cork oak bark is a renewable resource, and it grows again within a few years, so its extraction is an absolutely ecological process that guarantees the preservation of each tree. The largest producer of natural cork is AMORIM CORK, so we aim to cooperate with AMORIM. An ecological effect is expected.	To cooperate with the company, it is necessary to sign an agreement with the general director Carlos de Jesus. Airfare costs UAH 40,000/both ways and accommodation at the "Premier Hotel Odessa" hotel - UAH 7,000/2 days. A total of UAH 47,000.

Expansion of the raw material base	As a result of Russia's occupation of Crimea in 2014, Ukraine lost hundreds of thousands of hectares of vineyards, in 2022 it provoked the threat of extermination of vineyards located in the temporarily occupied Mykolaiv and Kherson regions. Expansion of the raw material base by increasing the area of vineyards. A decrease in the company's dependence on suppliers is expected.	1,000 hectares of land for vineyards in the Odesa region costs 270,000 UAH, respectively, 5,000 hectares - 1,350,000 UAH. A high-quality grape vine for the production of cognacs costs UAH 235/piece, 1,000 pieces are needed to start. - UAH 235,000. Staff - 20 people, payment per day 600 hryvnias. taking into account EUV - 96 thousand hryvnias. Total - UAH 1,681,000.
Release of family brandy collections	The collection is exclusive. Such a name will be associated with the value of the family, and for the first collection, selected grapes of a successful harvest from the best plots will be used, for which an exclusive assemblage will be chosen. The first such collection will be for the Shustovy family, the founders of the plant, and will be aged for 3 years. The expected effect is an increase in sales volume.	Purchase of grape varieties: such as Montils and Colombard, seedlings cost UAH 95.79 thousand. Costs for oak barrels for aging finished products. We need 3-4 oak barrels of 150 l, - 22 thousand UAH. Heraldry expert services (for design development) – UAH 37,000. Total - UAH 154.79 thousand.
Opening of branded stores throughout Ukraine	Branded stores make it possible to ensure a positive image on the market, brand recognition, and with high quality products and a balanced price policy, the expansion of sales markets and increase in sales volumes. The expected effect is an increase in the company's products on the market.	Initial costs: Premises measuring 86 m2 for a store - UAH 877.2 thousand/3 months. Equipment purchase costs - UAH 307,000. Working capital - UAH 921,000. Advertising costs (1 month): "Lightbox" sign - UAH 7,000. Advertising in social networks (Facebook, YouTube, Instagram). Creation of a 10-second video - 7.89 thousand UAH, promotion of the video - 3 thousand UAH/week, we plan 4 weeks = 12 thousand UAH. Total - UAH 19.89 thousand. Creating a store website - UAH 16,000. The cost of printing flyers is UAH 7.4 thousand. W/p with EUV to promoters - 13.5 thousand hryvnias. Total expenses for advertising - UAH 56.39 thousand. Total - UAH 2161.59 thousand.

To justify the feasibility of our proposed measures, we performed calculations and analyzed the effectiveness of their application. The expected effect of each measure is different, it is ensuring that the break-even point is reached, increasing the export of products, it is also increasing the volume of sales, reducing dependence on suppliers, increasing the availability of our company's products, or the opportunity to become ecologically modern.

V. CONCLUSIONS

In the course of the study, the theoretical and methodological foundations of the development of the company's development strategy were analyzed, a strategic analysis was performed, and measures aimed at maintaining the strategy of concentrated and integrated growth were proposed.

An analysis of the cognac production market was conducted and it was established that PJSC «OKZ» is the leader in cognac production in Ukraine, occupying 20% of the market.

The analysis of the main economic indicators of activity made it possible to conclude that in recent years there has been a positive growth of the main indicators of activity, namely net income.

In the course of the study of the strategic management toolkit of PJSC «OKZ», weaknesses that need improvement were identified and ways to improve them were proposed. It is proposed to use and implement a survival strategy. The following measures have been developed:

1. Introduction of production of products from the low-price segment.
2. Creation of a new TM «Ukrainian brandy» for entering the foreign market of ordinary cognacs, which will allow us to conquer a new segment of the foreign market through the associative series of our country's culture.
3. Organization of cooperation with Ukrainian restaurant chains. Wholesale sales and cooperation with large network customers make it possible to press into the market of new areas through collaborations and search for a possible future new consumer.

These measures will help to maintain a leadership position in the domestic market during wartime and will be able to support PJSC «OKZ» in a state of break-even operations.

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CHAOS & CHALLENGES IN UKRAINE: MODELING HR MANAGEMENT STRATEGY

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Abstract. *The current state of HR management strategy in Ukrainian companies can vary depending on the size and type of the company, the industry sector, and the location. However, in general, some of the key challenges faced by HR managers in Ukrainian companies include high turnover rates, a shortage of qualified candidates, low salaries, bureaucratic obstacles, cultural differences, remote work and lack of HR policies.*

The goal of this study is to show that Ukrainian companies have some problems and how they can focus on developing strategies to improve employee engagement and job satisfaction, employee development and career growth, while also focusing on the integration of Artificial intelligence into HR management.

The main method to solve out problems is an effective HR strategy, which aligns with the business objectives and is driven by clear objectives and goals. This includes developing recruiting strategies to identify, assess, and attract key talent; providing competitive benefits and development programs; mitigating risks associated with organization changes such as workforce restructuring or mergers; and using data analytics to proactively monitor performance.

As we can see, the key to create an effective HR management strategy for a Ukrainian company is to be aware of the specific challenges that the company is facing and to develop targeted solutions that are aligned with the company's overall business strategy and goals.

Key words**:** *HR management strategy, challenges, research, practices, solutions, development, goals.*

I. INTRODUCTION

The current state of HR management strategy in Ukrainian companies can vary depending on the size and type of the company, the industry sector, and the location. However, in general, some of the key challenges faced by HR managers in Ukrainian companies include high turnover rates, a shortage of qualified candidates, low salaries, bureaucratic obstacles, cultural differences, remote work and lack of HR policies.

A study by the Ukrainian Association of Personnel Management (UAPM) found that the average turnover rate in Ukraine was 21.7% in 2020, and that the average salary in Ukraine in 2020 was UAH 9,100 (about $321) per month. The study also found that only 40% of companies in Ukraine have a written HR policy. (Source: "Ukraine 2020: Labour market and HR trends", UAPM, 2020).

A survey conducted by DOU.ua found that the main challenges for IT companies in Ukraine are the lack of specialists and high employee turnover. (Source: "IT Industry in Ukraine: Challenges and Opportunities", DOU.ua, 2020)

A study by the European Business Association (EBA) found that the process of hiring and firing employees in Ukraine is one of the most time-consuming and bureaucratic in the region, taking an average of 39 days and requiring 20 different steps. (Source: "Doing Business in Ukraine 2020", European Business Association, 2020).

A survey by the Ukrainian Association of Remote Work found that companies are struggling with communication and coordination issues, as well as a lack of trust in remote employees. (Source: "Remote Work in Ukraine: Challenges and Opportunities", Ukrainian Association of Remote Work, 2021)

In general, Ukrainian companies are focusing on developing strategies to improve employee engagement and job satisfaction, employee development and career growth, and corporate social responsibility, while also focusing on the integration of Artificial intelligence into HR management.

Overall, the current state of HR management strategy in Ukrainian companies is marked by a number of challenges, including high turnover rates, a shortage of qualified candidates, low salaries, bureaucratic obstacles, cultural differences, remote work, and lack of HR policies. However, companies are also focusing on developing strategies to improve employee engagement and job satisfaction, employee development and career growth, and corporate social responsibility.

II. LITERATURE ANALYSIS

"Human Resource Management in Ukraine: An Overview" by Olga Kostyukevych and Nataliya Ryzhkova (2015) provides an overview of the current state of HR management in Ukraine, highlighting key challenges and best practices. The authors suggest that companies in Ukraine need to focus on developing effective recruitment and retention strategies, as well as providing training and development opportunities for employees. (Source: "Human Resource Management in Ukraine: An Overview" by Olga Kostyukevych and Nataliya Ryzhkova, Journal of Business Economics and Management, 2015).

"HR Management in Ukraine: Challenges and Opportunities" by Nataliya Vinnik and Olga Kostyukevych (2016) explores the challenges and opportunities faced by HR managers in Ukraine. The authors suggest that companies in Ukraine need to focus on developing effective recruitment and retention strategies, as well as providing training and development opportunities for employees. They also stress the importance of building a positive corporate culture and effective communication within the company. (Source: "HR Management in Ukraine: Challenges and Opportunities" by Nataliya Vinnik and Olga Kostyukevych, Journal of Business Economics and Management, 2016).

"HR Management in Ukraine: Current Status and Future Prospects" by Oksana Shyshkina and Olena Kudinova (2017) examines the current status and future

prospects of HR management in Ukraine. The authors suggest that companies in Ukraine need to focus on developing effective recruitment and retention strategies, as well as providing training and development opportunities for employees. They also stress the importance of building a positive corporate culture and effective communication within the company. (Source: "HR Management in Ukraine: Current Status and Future Prospects" by Oksana Shyshkina and Olena Kudinova, International Journal of Human Resource Management, 2017).

"Human Resource Management in the IT Industry in Ukraine: Current Status and Future Prospects" by Olga Kostyukevych and Nataliya Ryzhkova (2018) examines the current state of HR management in the IT industry in Ukraine and identifies key challenges and best practices. The authors suggest that companies in the IT industry in Ukraine need to focus on developing effective recruitment and retention strategies, as well as providing training and development opportunities for employees. They also stress the importance of building a positive corporate culture and effective communication within the company. (Source: "Human Resource Management in the IT Industry in Ukraine: Current Status and Future Prospects" by Olga Kostyukevych and Nataliya Ryzhkova, Journal of Business Economics and Management, 2018).

These literature reviews provide an insight into the current state of HR management and strategy in Ukrainian companies and the challenges faced by HR managers in Ukraine. They also highlight the importance of effective recruitment and retention strategies, providing training and development opportunities, building a positive corporate culture, and effective communication within the company.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

Object:

- employees of the organization;
- working conditions;
- staff structure.

In addition, the object of strategic management is the technology of HR management (technology of realization of labor potential, reproduction and development of personnel). Together, they form the labor potential of the organization.

Personnel strategy is a functional strategy, which is a system of training, retraining, selection, placement and training of personnel, adequate to the requirements of corporate, competitive and functional strategies of the enterprise, capable of strategic thinking and actions.

The subject of personnel strategy is the system of management bodies, which includes HR management services, structural divisions of the enterprise, united according to the principle of functional subordination, and line managers at all levels of management. The successful implementation of the personnel strategy is largely determined by the personnel's ability for productive and creative work, intellectual development, generation of new ideas, acquisition of new knowledge and development of skills, which together constitute the personnel potential of the enterprise under the condition of interaction of various elements of corporate culture.

The methodological toolkit of the research is based on general scientific and special methods, which ensure a comprehensive and objective nature of their study. In this work we used methods of systematic, logical analysis for the formation of goals and ways of implementing the HR management strategy and the generalization method for determining the levels of strategic HR management. The scientific works of scientists in the field of strategic enterprise management, HR management and management psychology became the theoretical basis of the research.

The main methodological principles of research include: principles of objectivity, scientificity, development and interaction, relativity, integrity, practicality, etc. The principle of objectivity is based on the current reflection of reality.

In addition, these are the following methods which were used in the research process: theoretical generalization - to clarify the conceptual apparatus regarding enterprise HR management; statistical analysis - for studying, grouping and comparing empirical data for the purpose of researching trends in the development of personnel potential. An empirical research method was used too.

The task of theoretical research is to give a complete picture of the phenomenon under study, to reveal the internal mechanism of the phenomenon. Theoretical research operates with ideal objects.

Statistical analysis – analysis of statistical data on mass phenomena and processes in the socio-economic sphere, nature, science, technology with the aim of establishing regularities of the state and development of these phenomena and processes, the connection between them, structural shifts, their forecasting.

The empirical method of research is one of the types of cognitive activity aimed at identifying connections in the object under study, while the essence of these connections provides a theoretical approach. The empirical approach is based on research and observation.

IV. RESULTS

Results of authors' research are presented in a table below through compiling a model of an HR management strategy for Ukrainian companies.

Table 1

Model of an HR management strategy for Ukrainian companies

№	Contemporary challenges in HR management in Ukraine	HR trends in Ukraine	HR best practices in Ukraine	Modeling an HR management strategy for Ukrainian companies would involve several key steps	Potential opportunities for future research in the area of HR management strategy in Ukrainian companies
1	High turnover rate	Remote work	Developing effective recruitment and retention	Identifying the key HR challenges	Talent management

			strategies		
2	Lack of qualified candidates	Employee engagement	Providing training and development opportunities	Conducting a SWOT analysis	Employee engagement
3	Low salaries	Employee development and career growth	Building a positive corporate culture	Developing objectives	Diversity and inclusion
4	Bureaucratic obstacles	Corporate social responsibility	Implementing effective communication	Implementing solutions	Change management
5	Cultural differences	Artificial intelligence	Streamlining bureaucratic procedures	Monitoring and evaluating progress	HR metrics
6	Remote work	Employee benefits	Providing cultural sensitivity training	Communicating the strategy	Remote work Training and development
7	Lack of HR policies	Flexible working hours	Implementing remote work policies Developing a written HR policy	Continuously improve	Cross-cultural management Employer branding

Contemporary challenges in HR management in Ukraine

In 2023, HR managers in Ukraine are facing a unique set of challenges due to the ongoing conflict in the country. Companies have had to adapt to the changing circumstances, with many reducing their number of employees and some having to relocate their management teams. This has caused a great deal of stress and anxiety among employees, leading employers to make mental health programs and resources available to their staff. At the same time, employers need to prioritize real-time support and assistance of employees, review of employee number and structure, strategic planning and management of change, and employee experience management. This is all the more important as employers strive to get the most out of their employees and create a positive work environment.

Among the most important challenges in HR management in Ukraine are the following:

- High turnover rate: Ukraine has a high employee turnover rate, which can be costly for companies and can make it difficult to maintain a stable workforce. A study by the Ukrainian Association of Personnel Management (UAPM) found that the average turnover rate in Ukraine was 21.7% in 2020 (Source: "Ukraine 2020: Labour market and HR trends", UAPM, 2020).

- Lack of qualified candidates: There is a shortage of qualified candidates for many positions, especially in the IT industry. A survey conducted by DOU.ua found that the main challenges for IT companies in Ukraine are the lack of specialists and high employee turnover (Source: "IT Industry in Ukraine: Challenges and Opportunities", DOU.ua, 2020).
- Low salaries: Salaries in Ukraine are generally lower than in Western countries, which can make it difficult to attract and retain top talent. According to the Ukrainian Association of Personnel Management (UAPM), the average salary in Ukraine in 2020 was UAH 9,100 (about $321) per month (Source: "Ukraine 2020: Labour market and HR trends", UAPM, 2020).
- Bureaucratic obstacles: The process of hiring and firing employees in Ukraine can be bureaucratic and time-consuming. A study by the European Business Association (EBA) found that the process of hiring and firing employees in Ukraine is one of the most time-consuming and bureaucratic in the region, taking an average of 39 days and requiring 20 different steps (Source: "Doing Business in Ukraine 2020", European Business Association, 2020).
- Cultural differences: Companies may face challenges related to cultural differences when managing employees from different backgrounds. A study by the Ukrainian Institute of Social Studies found that cultural differences can lead to misunderstandings and conflicts between employees from different backgrounds and that companies need to be aware of these differences and take steps to manage them effectively (Source: "Cultural Diversity in the Ukrainian Labour Market", Ukrainian Institute of Social Studies, 2018).
- Remote work: With the pandemic, many companies in Ukraine are now facing the challenges of remote work, such as communication, coordination and productivity. A survey by the Ukrainian Association of Remote Work found that companies are struggling with communication and coordination issues, as well as a lack of trust in remote employees (Source: "Remote Work in Ukraine: Challenges and Opportunities", Ukrainian Association of Remote Work, 2021).
- Lack of HR policies: Many companies in Ukraine lack well-defined HR policies and procedures, which can lead to confusion and inconsistency in how employees are treated. A study by the Ukrainian Association of Personnel Management (UAPM) found that only 40% of companies in Ukraine have a written HR policy (Source: "Ukraine 2020: Labour market and HR trends", UAPM, 2020).

To summarize the available information, in Ukraine, human resources management is currently faced with a variety of challenges, such as employee confusion and safety. At the same time, ensuring the continuity of work processes and meeting the demands of the changing labor market are also a concern. Employers have been called to take action in light of the ongoing conflict, with experts recommending taking a stance on the crisis and providing employees with mental health resources and programs. Mental health is increasingly becoming a priority in Ukraine, as the conflict brings more stress and anxiety to the workplace. The main focus for HR managers in 2023 hold real-time maintenance and help of employees (55%), revision of employee

number and structure (38%), workload management (38%), and the design and adoption of employee welfare programs (38%) (Source: “Approaches to human capital management in Ukraine”, Deloitte, 2023).

HR trends in Ukraine

With the ongoing full-scale war in Ukraine, the HR function has become increasingly important. HR teams will be focusing on a range of priorities this year, such as maintaining employee engagement and performance as budgets tighten, developing conscious leadership, building change resilience, managing employees in a digital world and having a frank and candid dialogue with employees.

Among HR trends in Ukraine are the following:

- Remote work: With the COVID-19 pandemic, remote work has become more popular in Ukraine. A survey by the Ukrainian Association of Remote Work found that more than 60% of companies in Ukraine have implemented remote work policies (Source: "Remote Work in Ukraine: Challenges and Opportunities", Ukrainian Association of Remote Work, 2021).
- Employee engagement: Employee engagement has become a key focus for companies in Ukraine. A study by the Ukrainian Institute of Social Studies found that companies in Ukraine are focusing on developing strategies to improve employee engagement and job satisfaction. (Source: "Employee Engagement in Ukraine: Current Status and Future Prospects", Ukrainian Institute of Social Studies, 2020).
- Employee development and career growth: Employee development and career growth is becoming a key focus for companies in Ukraine. A study by the Ukrainian Institute of Social Studies found that companies in Ukraine are focusing on developing strategies to improve employee development and career growth. (Source: "Employee Development and Career Growth in Ukraine", Ukrainian Institute of Social Studies, 2019).
- Corporate social responsibility: Corporate social responsibility has become an important trend in Ukraine. A study by the Ukrainian Institute of Social Studies found that companies in Ukraine are focusing on developing strategies to improve corporate social responsibility and sustainability. (Source: "Corporate Social Responsibility in Ukraine: Current Status and Future Prospects", Ukrainian Institute of Social Studies, 2018).
- Artificial intelligence: Artificial intelligence has become a key trend in Ukraine. A study by the Ukrainian Institute of Social Studies found that companies in Ukraine are focusing on developing strategies to integrate artificial intelligence into HR management. (Source: "Artificial Intelligence in HR management in Ukraine: Current Status and Future Prospects", Ukrainian Institute of Social Studies, 2017).
- Employee benefits: Employee benefits have become an important trend in Ukraine. A study by the Ukrainian Institute of Social Studies found that companies in Ukraine are focusing on developing strategies to improve employee benefits to attract and retain top talent. (Source: "Employee Benefits in Ukraine: Current Status and Future Prospects", Ukrainian Institute of Social Studies, 2016).

- Flexible working hours: Flexible working hours have become an important trend in Ukraine. A study by the Ukrainian Institute of Social Studies found that companies in Ukraine are focusing on developing strategies to improve flexible working hours to improve employee engagement and job satisfaction. (Source: "Flexible Working Hours in Ukraine: Current Status and Future Prospects", Ukrainian Institute of Social Studies, 2015).

These are some of the main trends in HR management in Ukraine. It's important to note that these trends may vary depending on the size and type of the company, the industry sector, and the location.

HR best practices in Ukraine

Amid the conflict in Ukraine, there is an increased need for HR best practices in order to support employees and families. Employers must ensure physical safety and psychological safety of their employees, which can be achieved through strong communication, mental health efforts, charitable programs, and more. Additionally, HR professionals must work to personalize work for employees, such as by offering flexible work arrangements that fit their unique needs. This can also be achieved by having open conversations with employees to better understand their needs and how to best support them. By following these best practices, employers can ensure that their staff feel valued and supported in a time of crisis.

Developing effective recruitment and retention strategies is a good practice to address the challenges of high turnover and a shortage of qualified candidates, companies in Ukraine should focus on developing effective recruitment and retention strategies. It was found that companies in Ukraine that focus on employee development and career growth have lower turnover rates. (Source: "Ukraine 2020: Labour market and HR trends", UAPM, 2020).

Providing training and development opportunities can help to improve employee skills and increase job satisfaction. It was researched that companies in Ukraine that provide training and development opportunities have higher levels of employee engagement and job satisfaction. (Source: "Employee Development and Career Growth in Ukraine", Ukrainian Institute of Social Studies, 2019).

Building a positive corporate is aimed to improve employee engagement and job satisfaction. It was found that companies in Ukraine that have a positive corporate culture have higher levels of employee engagement and job satisfaction. (Source: "Corporate Culture and Employee Engagement in Ukraine", Ukrainian Institute of Social Studies, 2018).

Implementing effective communication within the company can help to improve employee engagement and job satisfaction. A study by the Ukrainian Institute of Social Studies stresses that companies in Ukraine that have effective communication have higher levels of employee engagement and job satisfaction. (Source: "Communication and Employee Engagement in Ukraine", Ukrainian Institute of Social Studies, 2017).

Streamlining bureaucratic procedures could make the process of hiring and firing employees more efficient. There was researched that companies in Ukraine that

have streamlined bureaucratic procedures have lower turnover rates and higher levels of employee engagement. (Source: "Doing Business in Ukraine 2020", European Business Association, 2020).

Providing cultural sensitivity training can help to improve communication and collaboration between employees from different backgrounds. A study found that companies in Ukraine that provide cultural sensitivity training have lower turnover rates and higher levels of employee engagement. (Source: "Cultural Diversity in the Ukrainian Labour Market", Ukrainian Institute of Social Studies, 2018).

With the pandemic, many companies in Ukraine are now facing the challenges of remote work. A survey by the Ukrainian Association of Remote Work explored that companies in Ukraine that have implemented effective remote work policies have higher levels of employee engagement and job satisfaction. (Source: "Remote Work in Ukraine: Challenges and Opportunities", Ukrainian Association of Remote Work, 2021).

Developing a written HR policy could ensure that employees are treated consistently and fairly. (Source: "Ukraine 2020: Labour market and HR trends", UAPM, 2020).

Modeling an HR management strategy for Ukrainian companies

The success of companies in Ukraine in 2023 will depend heavily on their strategic HR management practices. To remain competitive and compliant with the changing legal, economic, and technological landscape, Ukrainian companies need to have well-defined HR management models that are tailored to their specific needs and goals.

Modeling an HR management strategy for Ukrainian companies would involve several key steps:

1. Identifying the key HR challenges: The first step in creating an HR management strategy is to identify the specific challenges that the company is facing, such as high turnover rate, lack of qualified candidates, low salaries, bureaucratic obstacles, cultural differences, remote work, and lack of HR policies.

2. Conducting a SWOT analysis: Conducting a SWOT analysis (Strengths, Weaknesses, Opportunities, and Threats) can help the company to identify its internal strengths and weaknesses, as well as external opportunities and threats that may impact the HR management strategy.

3. Developing objectives: Based on the challenges identified and the SWOT analysis, the company should develop clear and measurable objectives for its HR management strategy. These objectives should be aligned with the company's overall business strategy and goals.

4. Implementing solutions: Once the objectives have been developed, the company can begin implementing solutions to address the identified challenges. This may include developing new recruitment processes, implementing employee retention programs, offering competitive salary packages, streamlining bureaucratic procedures, providing cultural sensitivity training, and implementing remote work policies.

5. Monitoring and evaluating progress: Regularly monitoring and evaluating the progress of the HR management strategy is essential to ensure that the objectives are being met and to identify any areas that may need to be adjusted.

6. Communicating the strategy: Communicating the strategy to all employees, managers, and stakeholders, will help ensure that everyone is aware of the company's goals and objectives, and that they understand their role in achieving them.

7. Continuously improve: Continuously improving the strategy by understanding the best practices and trends in the industry and adopt them as necessary.

Overall, the key to creating an effective HR management strategy for a Ukrainian company is to be aware of the specific challenges that the company is facing and to develop targeted solutions that are aligned with the company's overall business strategy and goals.

By following these steps, Ukrainian companies can create an effective HR management strategy that will help them remain competitive and successful in 2023. With the right people, processes, and technology in place, companies in Ukraine can develop a successful HR management strategy that will help them achieve their long-term goals.

Potential opportunities for future research in the area of HR management strategy in Ukrainian companies

There are a number of potential areas for future research in the field of HR management strategy in Ukrainian companies. Some possible areas of focus include:

- Talent management: Developing strategies for identifying, recruiting, and retaining top talent in Ukrainian companies.
- Employee engagement: Investigating ways to increase employee engagement and motivation in Ukrainian companies.
- Diversity and inclusion: Examining the state of diversity and inclusion in Ukrainian companies and identifying ways to promote more inclusive workplaces.
- Change management: Investigating how Ukrainian companies can effectively manage organizational change, particularly in the context of rapid economic and political changes in the country.
- HR metrics: Developing methods for measuring the effectiveness of HR strategies in Ukrainian companies and using data to inform decision-making.
- Remote work: Exploring the impact of remote work on HR management strategies, employee engagement, and productivity in Ukrainian companies.
- Cross-cultural management: Investigating how Ukrainian companies can effectively manage a diverse workforce, including employees from different cultural backgrounds.
- Employer branding: Examining the role of employer branding in attracting and retaining top talent in Ukrainian companies.
- Training and development: Identifying effective training and development strategies for Ukrainian employees, particularly in the context of digitalization and Industry 4.0.

- Compliance with labor laws and regulations: Analyzing the current state of compliance with labor laws and regulations in Ukrainian companies and identifying ways to improve compliance.

As the geopolitical situation in Ukraine continues to develop, HR leaders in Ukrainian companies will need to prepare for what comes next. With the ever-changing landscape, it is important to remain up to date on the best strategies to ensure the wellbeing of employees. In 2023, the research focus in the area of HR management strategy in Ukrainian companies will be to ensure that the best possible practices are being implemented. This research should focus on topics such as remote work, digitalization, staff empowerment, and other topics related to employee wellbeing. Additionally, research should also consider the impact of the geopolitical situation on the workforce and how HR can best support employees in times of crisis. Research should also provide a curated list of resources that firms can use to support employees and fellow humans impacted by the war unfolding in Ukraine. Such resources may include memos from HR directors on the crisis, articles on how to support employees, and a list of actions that companies can take to support their workers.

V. CONCLUSIONS

The development of Ukraine's HR management strategy will depend largely on the country's overall economic and political situation. With the right investments in education, infrastructural development, and social policies, Ukraine has the potential to build a strong and efficient HR system.

The current state of HR management strategy in Ukrainian companies is marked by a number of challenges, including high turnover rates, a shortage of qualified candidates, low salaries, bureaucratic obstacles, cultural differences, remote work, and lack of HR policies. However, companies are also focusing on developing strategies to improve employee engagement and job satisfaction, employee development and career growth, and corporate social responsibility.

The HR management strategy should encompass all aspects of human resources. An effective HR strategy should align with the business objectives and be driven by clear objectives and goals. This includes developing recruiting strategies to identify, assess, and attract key talent; providing competitive benefits and development programs; mitigating risks associated with organization changes such as workforce restructuring or mergers; and using data analytics to proactively monitor performance.

As for literature reviews, they provide an insight into the current state of HR management and strategy in Ukrainian companies and the challenges faced by HR managers in Ukraine. They also highlight the importance of effective recruitment and retention strategies, providing training and development opportunities, building a positive corporate culture, and effective communication within the company.

The trends that are indicated above are some of the main trends in HR management in Ukraine. It's important to note that these trends may vary depending on the size and type of the company, the industry sector, and the location.

As we can see, the key to creating an effective HR management strategy for a Ukrainian company is to be aware of the specific challenges that the company is facing

and to develop targeted solutions that are aligned with the company's overall business strategy and goals.

Overall, despite the fact that there are quite a lot of problems and challenges in Ukraine, our companies are trying to find the most effective solutions to overcome difficulties and create a favorable environment for work. We believe that the big changes are coming, and it will help us to transform into something a lot more integral and better in general.

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THE SOCIO-ECONOMIC DETERMINANTS OF GREEN BOND ISSUANCE

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Summary. *Global awareness of the climate change risks draws society's attention to issues of financing environmentally friendly projects. In this context, "green" bonds are a new financial instrument used exclusively for financing environmentally friendly projects. A wide range of issuers, from small firms to international corporations, can use "green" bonds to raise funds for environmentally friendly projects. In recent years, the "green" bonds market has been developing rapidly in the world. Financing the recovery of Ukraine after the Russian invasion requires launching this market in Ukraine as well. This will increase the scope of infrastructure projects financing in the field of alternative energy and energy efficiency, reduce greenhouse gas emissions and consumption of fuel and energy resources, and improve Ukraine's investment attractiveness and competitiveness. The "green" bond market operates under the influence of numerous factors that have both direct and indirect effects on it. The research examines the relationship between the volume of "green" bond issuance in the different countries in 2021, when its jump-like growth took place, and the factors that characterize the environmental, social, governance and macroeconomic spheres of the countries. The research was conducted on the dataset of socio-economic indicators of 54 countries. The obtained results of the study indicate that countries with a higher volume of "green" bond issuance are primarily characterized by good credit ratings, which increases investor confidence, better economic development and a large population. Understanding the socio-economic determinants of "green" bond issuance will help market participants make informed decisions.*

Keywords*: sustainability, "green" bonds, issuance, socio-economic determinants, correlation and regression analysis.*

I. INTRODUCTION

The transition to a low-carbon economy requires significant investments, so the attention is focused on finding financial sources to fund environmentally friendly projects. Issuance of "green" bonds is an alternative to traditional sources of financing such projects. The International Capital Market Association defines "green" bonds as a bond instrument where the proceeds will be exclusively applied to finance or refinance, in part or full, new, or existing eligible green projects. These eligible "green" projects refer to the follows: renewable energy, energy efficiency, pollution prevention and control, environmentally sustainable management of living natural resources and land use, terrestrial and aquatic biodiversity conservation, clean transportation, sustainable water and wastewater management, climate change adaptation, eco-efficient and circular economy adapted products, production technologies, and processes and green buildings [1]. According to this definition, a wide range of issuers,

from small firms to international corporations, can use "green" bonds to attract funds for environmentally friendly projects.

In 2021, the global "green" bond market grew by 75% compared to 2020 and reached $578 billion (Fig.1).

Fig. 1. The dynamics of the issue of "green" bonds in the world [2]

The total number of issuers increased by 32%, reaching 839 issuers. The average volume of individual "green" bonds increased by 51%, reaching the mark of $250 million. This growth was facilitated by the addition of sovereign bonds from new and existing issuers [3]. In 2022, the "green" bond market continued to grow rapidly and exceeded the $2 trillion mark at the end of September 2022 [4].

"Green" bonds are a powerful financial instrument that is rapidly developing in the context of climate change risks. In this context, the introduction of a climate-neutral economy by 2050 is recognized as a priority of the European Union [5].

II. ANALYTIC OVERVIEW OF THE LITERATURE

The latest trends in economic demonstrate the concentration of scientists' attention on indicators of sustainable development. This is explained by the fact that in September 2015, within the framework of the 70th session of the UN General Assembly, the UN Summit on Sustainable Development was held in New York, the final document of which was 17 Goals of Sustainable Development and 169 objectives [6]. In this context, the issue of "green" bonds as a new powerful financing tool has become a topic that is widely discussed in the scientific community.

The dynamics of scientific publications in the field of "green" bond issuance over the past 5 years is shown in Fig.2, and their affiliation with countries – in Fig.3.

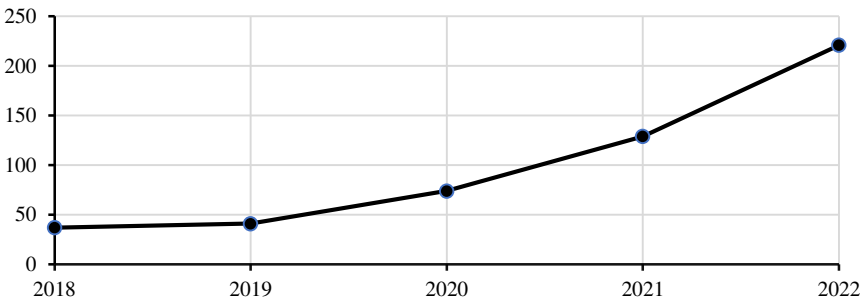

Fig. 2. Dynamics of scientific publications in the field of "green" bond issuance

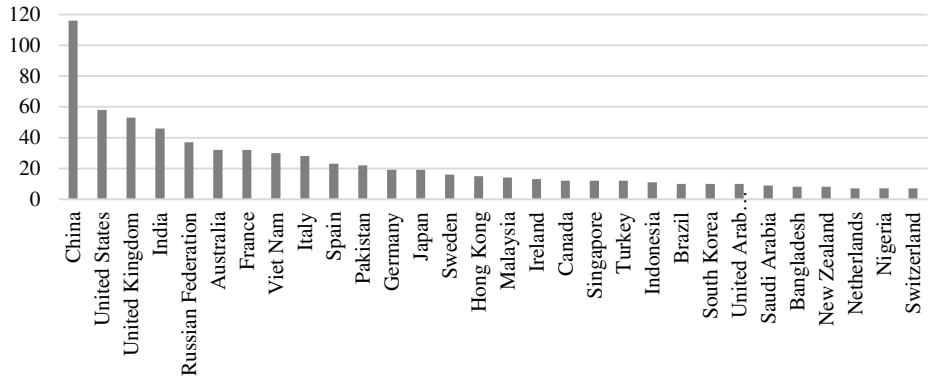

Fig. 3. Affiliation of scientific publications in the field of "green" bond issuance

The bibliometric analysis was carried out on the basis of a sample of 502 publications over the past 5 years, which was obtained from the Scopus database by the request TITLE-ABS-KEY("green bond*"). The largest number of scientific publications over the past 5 years belongs to scientists from countries that have issued the largest number of "green" bonds. In the USA, "green" bonds were issued in the amount of $334 billion, China - $250 billion, France – $189.7 billion, Great Britain - $53.3 billion [2].

The level of development of the "green" bond market in different regions of the world varies. In many countries, "green" bonds are still not issued. Today, the European market occupies a leading position in terms of the volume of issuance of "green" bonds, followed by the markets of the Asia-Pacific region and North America.

Halkos in his work [7] measured the interdependence between 96 countries of the world using network analysis. He established that the USA and European countries play a leading role in the market of "green" bonds and are their main issuers in terms of frequency and volume. Dan and Tiron-Tudor in [8] investigated the determinants of the issuance of "green" bonds in the countries of the European Union in the period 2014-2019 and established that the countries of the European Union with a larger volume of issuance of "green" bonds are characterized, first of all, by high credit ratings, which increase the confidence of investors, and a large number of the population, which forms the demand for investment projects, the implementation of which involves attracting significant financial resources. ESG (Environmental, Social and Governance) risk rating and inflation rate also affect the volume of green bond issuance. Despite the existing scientific publications, it could be stated that insufficient attention is paid to the study of socio-economic determinants of the emission of "green" bonds in the world, especially during the period of rapid growth of their volume.

III. OBJECT, SUBJECT AND RESEARCH METHODS

The object of the study is the "green" bond market. The subject of the study are socio-economic determinants of "green" bond issuance. With the aim of examining the relationship between the volume of "green" bond issuance in the world in 2021, when its jump-like growth took place, and the factors that characterize the environmental, social, governance and macroeconomic spheres of the countries, 7 independent variables were used. There are environmental, social, and governance risk index

(ESG), credit rating, trade openness, unemployment rate, inflation, GDP per capita, population. Correlation and regression analysis was used to determine the cause-and-effect relationship between variables, as well as the variables that have the greatest impact on the volume of "green" bond issuance.

IV. RESULTS OF THE WORK

4.1. Database description and variables

To determine the socio-economic determinants of the emission of "green" bonds in the world in 2021, a linear regression model, which is based on previous studies [8] was built. As a dependent variable (*bonds_value*), the amount of funds in US dollars raised through the issuance of "green" bonds in each of the 54 studied countries in 2021 was taken. The data were obtained from the Climate Bond Initiative database [2]. The independent variables were selected based on the analysis of scientific publications in the field of "green" bond issuance and are detailed in Table 1.

Tab. 1. Independent variables of the regression model

Independent variable	Variable description	Data source
ESG_risk	Environmental, social and governance (ESG) risk rating of the issuer's country of residence	[9]
credit_rating	Credit rating of the issuer's country of residence (ordinal scale)	[10]
trade_openness	Trade openness, measured as the level of exports of goods and services (% of GDP)	[11]
unemployment_rate	Unemployment rate in the issuer's country of residence, %	[11]
inflation	Consumer price index (CPI, 2010=100%)	[12]
GDP_per_capita	GDP of the issuer's country of residence per capita at purchasing power parity in international dollars	[11]
population	Population in the country, persons	[11]

Environmental, Social, and Governance risk index (ESG). By now, investors move their attention to more soft aspects like environmental, social, and governance performance indicators when they decide to invest. ESG criteria are closely related to corporate social responsibility and socially responsible investment objectives [13]. The empirical studies reveal that the ESG indicators positively affect the bond market because of lower borrowing costs [14-17]. Other researchers analyzed the impact of ESG on the interest cost in the Chinese "green" bonds market and showed that a higher ESG score led to lower yield spreads, a better financial condition, and a long-term orientation [18]. Additionally, the extra financial performance has important economic roles at the country level. This supposed that countries have a long-term orientation, collaborate, and communicate with outside parties, leading to an increase in investor's trust. Besides, act as a buffer against adverse shocks, which is perceived as an extra guard against possible losses. ESG risk index provided by CountryRisk.io explains

how its components will affect the long-term sustainability of a country. If the risk is higher, there is a more increased need for financing.

Rating. Credit rating agencies are an independent organization that analyzes an issuer's creditworthiness using various information. It is well known that credit ratings have a significant influence on the bond market. The issuer's credit rating impacts the investment decision in green bonds, and the issuer can attract more investors if they have good ratings [19]. This fact leads by default to a large amount of "green" bond issues. Chiesa and Barua revealed the positive influence of rating on the issue amount [20]. Low ratings are associated with higher financing costs since it presents the issuer's ability to repay their debt and access capital market. A consequence of a low credit rating is a high cost of funding, as it demonstrates the ability of the issuer to repay its debt and access the capital market [21]. The sovereign rating provided by Fitch was used and converted into ordinal scale from 0 (DD) to 21 (AAA) following [22].

Trade openness. Trade openness represents the connection with the rest of the world. Tolliver found that trade openness led to the growth of the green bond market [23]. Previous studies also demonstrate that trade openness has an impact on financing costs. The prominence of this macroeconomic indicator increased after the financial crisis, when the researcher findings had revealed that a higher level of trade openness leads to lower bond spread.

Inflation rate. In the literature, the inflation rate is perceived as the quality of economic management that directly influences the default risks. Nickel stated that higher inflation rates lead to macroeconomic instability that lowers the government's creditworthiness [24]. Also, the inflation rate plays an essential role in accessing long-term finance by new EU countries [25]. Furthermore, Presbitero found that higher inflation leads to a lower probability of issuing government bonds, and the issuances will have a higher borrowing cost [26]. The inflation rate is a financial factor that influences the green market expansion, a higher level of inflation negatively affects the investor's decisions [27]. In addition, analyzing the OECD members Tu and Rasoulinezhad found that inflation has a negative and significant impact on energy efficiency [28]. Therefore, investors consider inflation when they decided to finance energy efficiency projects.

Unemployment rate. The development of the green bond market is also linked with social factors like the unemployment rate. So, using the analytic hierarchy process, Anh Tu found that expert's judgments consider the unemployment rate as a factor of influence of the issuance of green bonds [27]. The literature reveals that higher unemployment rates lead to an increase in the debt level obtained with higher costs [29].

Gross domestic product per capita (GDP_per_capita). The capacity to issue green bonds is positively influenced by the economy's size [23]. Analyzing the drivers of issuance of sovereign bonds in developing countries, Presbitero found that economic size, and higher per capita GDP characterize countries that frequently issue bonds [26]. Also, Glomsrød and Wei also found that when green financing increases, the GDP levels increase worldwide. The level of growth is more pronounced in the European Union [30].

Population. A large population constitutes an increasing demand for investment projects, which implies considerable financial resources. Green bonds can be used to attract money from investors to finance environmentally friendly projects. However, in countries with low population density, the green projects have a small size [31]. The country size is measure by the population number. Presbitero found that the population positively influences the issue of government bonds [26].

4.2. Summary statistics and statistical analysis of data

The software used for the model building was Stata 17. A statistical description of the independent variables of the model is presented in Fig.4.

Variable	Obs	Mean	Std. dev.	Min	Max
bonds_value	54	9.88e+09	1.88e+10	7000000	9.00e+10
ESG_risk	54	28.65444	14.72719	3.92	73.1
credit_rat~g	54	15.25926	4.622281	4	21
trade_open~s	54	51.03961	38.39947	9.981151	212.1172
unemployme~e	54	6.582407	4.169369	.07	27.48
inflation	54	136.2247	40.41135	100	314.81
GDP_per_ca~a	54	43680.97	27635.29	5877.64	134753.8
population	54	1.00e+08	2.67e+08	287708	1.41e+09

Fig. 4. Descriptive statistics of the independent variables of the model

The average volume of "green" bond issuance is $9.88 billion, with a range of $0.007 to $90 billion.

Significant discrepancies were found in the rating assessment of ESG risk. Switzerland, Germany, Norway, Sweden, and Denmark have the lowest values of this assessment. The highest are Pakistan, Argentina, Greece, and Brazil.

Argentina, Pakistan, and Ukraine have the lowest values of the credit rating assessment. The highest are Australia, Denmark, Germany, Norway, USA, Switzerland, Sweden. The average value of this grade is very high and equals 15 (A-).

Trade openness (export of goods and services as a percentage of GDP) averages 51%. There is a considerable variation between countries. Singapore has 185% while Pakistan has only 10%.

The highest levels of GDP per capita at purchasing power parity were registered in Luxembourg, Singapore, and Ireland. The lowest are in Pakistan and India.

Then we check the normality of the distribution of model variables using the Jacque-Bera and Shapiro-Wilk tests. The results are shown in Table 2. The proposed null hypothesis states that the corresponding variable has a normal distribution form. Variables for which the null hypothesis cannot be rejected are highlighted in bold.

Tab. 2. Testing for the normality of the distribution of the model variables

Independent variable	Jacque-Bera test		Shapiro-Wilk test		Is the shape of the distribution normal?
	χ^2	*p*-value	*W*	*p*-value	
bonds_value	203,500	0	0,56044	0	No
ESG_risk	**2,385**	**0,3034**	**0,9652**	**0,1178**	**Yes**
trade_openness	143,300	0	0,76045	0	No
credit_rating	**3,070**	**0,2155**	**0,9645**	**0,1092**	**Yes**
unemployment_rate	270,5	0	0,8096	0	No
inflation	250,00	0	0,6493	0	No
GDP_per_capita	16,220	0,0003	0,9165	0,0011	No
population	963,200	0	0,3628	0	No

There are few examples of testing for the normality of the distribution of the independent variables described below.

Dependent variable "*bonds_value*" was tested for normality with both the Jarque-Bera and Shapiro-Wilk tests. Both tests yielding *p*-values very close to 0 so we reject the null hypothesis that the variable is normally distributed (for α=0.05). Histogram of the distribution is presented in Fig. 5.

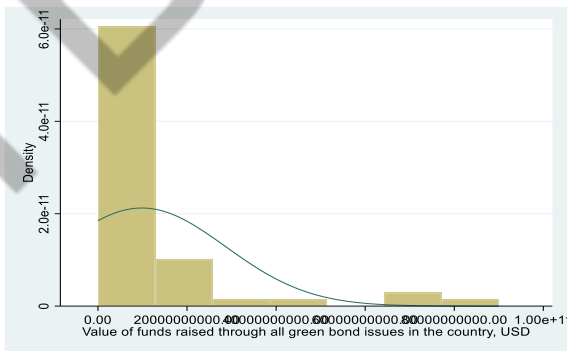

Fig. 5. Distribution of the dependent variable "*bonds_value*"

Independent variable "*ESG_risk*" was tested for normality with both the Jarque-Bera and Shapiro-Wilk tests. Both tests yielding *p*-values greater then 0.1 so we accept the null hypothesis that the variable is normally distributed (for α=0.1). Histogram of the distribution is presented in Fig. 6.

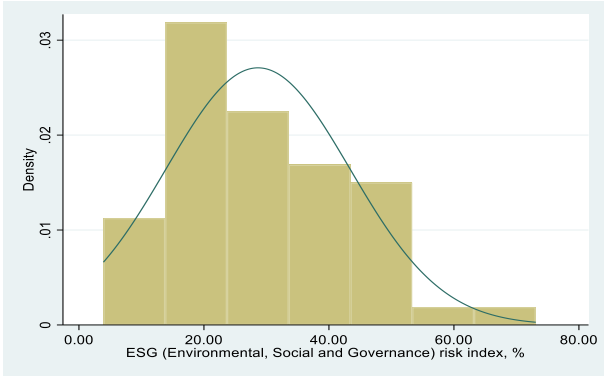

Fig. 6. Distribution of the independent variable "*ESG_risk*"

In the next step, the correlation between the independent variables and the dependent variable of the model was analyzed. Considering the results of the preliminary test for the normality of the distribution of the model variables, Spearman's rank correlation coefficient was used as a measure of correlation. The results of the test are shown in Table 3. Variables with a weak correlation with the dependent variable are highlighted in bold. They were excluded from further consideration.

Tab. 3. Testing for correlation of the independent variables

Independent variable	**Spearman's rank correlation coefficient**		**Is there a correlation?**
	value	***Prob > |t|***	
ESG_risk	-0,5263	0	Yes
trade_openness	**-0,1118**	**0,4207**	**No**
credit_rating	0,6251	0	Yes
unemployment_rate	**-0,1235**	**0,3738**	**No**
inflation	-0,4014	0,0026	Yes
GDP_per_capita	0,5289	0,0000	Yes
population	0,2486	0,0699	Yes

Note that according to the Chaddock scale, the values of the correlation coefficients have the following interpretation: 0.1÷0.3 – weak correlation; 0.3÷0.5 – moderate correlation; 0.5÷0.7 – noticeable correlation; 0.7÷0.9 – high correlation; 0.9÷1.0 – strong correlation.

4.3. Selecting a functional form

Box-Cox transformation is used to determine whether and which variables in the model should be logarithmically transformed. So, this transformation [32] was applied to the model variables for which the hypothesis of a normal form of distribution was not confirmed, to determine the type of their transformation. The results are shown in Table 4. Hence, variables "*bonds_value*", "*GDP_per_capita*", "*population*" should be logarithmically transformed.

Tab. 4. P-value of the Box-Cox transformation coefficient

Independent variable	$Prob > \chi^2$			Type of transformation
	$H_0: \lambda = -1$	$H_0: \lambda = 0$	$H_0: \lambda = 1$	
bonds_value	0,000	0,365	0,000	natural logarithm
inflation	0,000	0,000	0,000	–
GDP_per_capita	0,000	0,092	0,000	natural logarithm
population	0,000	0,931	0,000	natural logarithm

After the logarithmic transformation of the variables "*bonds_value*", "*GDP_per_capita*", "*population*", the parameters of the regression model were estimated by the method of ordinary least squares (Fig. 5).

Source	SS	df	MS	Number of obs	=	54
				F(5, 48)	=	20.67
Model	148.342983	5	29.6685966	Prob > F	=	0.0000
Residual	68.9114925	48	1.43565609	R-squared	=	0.6828
				Adj R-squared	=	0.6498
Total	217.254475	53	4.09914104	Root MSE	=	1.1982

log_bonds_value	Coefficient	Std. err.	t	P>|t|	[95% conf.	interval]
ESG_risk	.0345647	.0317881	1.09	0.282	-.0293496	.098479
credit_rating	.2408198	.1044389	2.31	0.025	.0308314	.4508083
inflation	.0030087	.0051909	0.58	0.565	-.0074283	.0134456
log_GDP_per_capita	1.641235	.4889218	3.36	0.002	.6581915	2.624278
log_population	.7758041	.1156618	6.71	0.000	.5432505	1.008358
_cons	-13.90836	6.510222	-2.14	0.038	-26.99804	-.8186845

Fig. 5. Estimated parameters of the constructed regression model

As it turned out, the variables "*ESG_risk*" and "*inflation*" have a *p*-value above the acceptable level of 0.05 and were excluded from further consideration.

4.4. Regression

The final regression equation with significant variables was obtained (Fig. 6).

Source	SS	df	MS	Number of obs	=	54
				F(3, 50)	=	34.38
Model	146.31857	3	48.7728566	Prob > F	=	0.0000
Residual	70.9359054	50	1.41871811	R-squared	=	0.6735
				Adj R-squared	=	0.6539
Total	217.254475	53	4.09914104	Root MSE	=	1.1911

log_bonds_value	Coefficient	Std. err.	t	P>|t|	[95% conf.	interval]
credit_rating	.1435692	.0632188	2.27	0.027	.0165905	.270548
log_GDP_per_capita	1.492665	.4689865	3.18	0.003	.5506781	2.434652
log_population	.7974753	.1126111	7.08	0.000	.5712892	1.023661
_cons	-9.834311	5.478962	-1.79	0.079	-20.83913	1.170509

Fig. 6. Estimated parameters of the final regression model

4.5. Potential problems with the data

The verification of the presence of collinearity between individual variables in the model, which could negatively affect the interpretation of the results, was carried out using the variance inflation factor (VIF). The critical value of VIF is usually taken as 5. The results of the test are shown in Table 5.

Tab. 5. Testing for multicollinearity

Independent variable	VIF
credit_rating	3,19
log_GDP_per_capita	4,06
log_population	1,52

Since the calculated VIF value is relatively low, it can be concluded that multicollinearity is absent in the constructed model.

4.6. Diagnostic tests

To check the accuracy and validity of the functional form of the model and to determine whether some of the key assumptions behind the properties of the OLS estimator are satisfied, the diagnostic tests were used.

The RESET Test

Since the available data sample is quite small, the Ramsey RESET test was used to test the functional form of the model only with the degrees of individual regressors, which confirmed the acceptability of the functional form of our model. The result of conducting Ramsey RESET Test is presented in Fig. 7.

```
Ramsey RESET test for omitted variables
Omitted: Powers of independent variables

H0: Model has no omitted variables

F(9, 41) =    0.73
Prob > F = 0.6775
```

Fig. 7. RESET Test output

The Breusch-Pagan and The White Tests

It should be noted that homoscedasticity is an important assumption, based on which the estimation of model parameters by the method of least squares is proved to be the best linear unbiased estimate (BLUE, Best Linear Unbiased Estimate). In the presence of heteroscedastic disturbances, this parameterization method may lose its effectiveness.

Testing for heteroskedasticity was performed using the Breusch-Pagan and White tests. Both tests confirmed the hypothesis of homoscedasticity of model residuals.

The Breusch-Pagan test yielded a *p*-value of 0.1306, which means that the null hypothesis cannot be rejected for α=0.05 or even α=0.1.

The White test yielded a *p*-value of 0.2334, which means that the null hypothesis cannot be rejected for α =0.05 or even α =0.1.

Analysis of Residuals

To analyze the residuals (versus normal distribution), the histogram was built (Fig.7). The shape of the distribution of residuals responds to normal distribution.

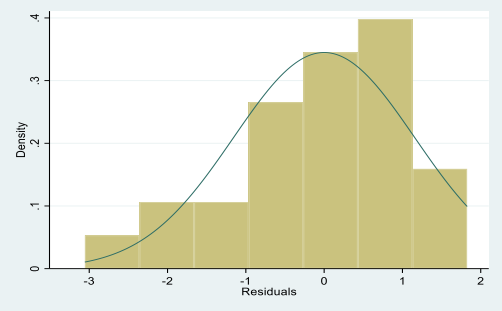

Fig. 7. The histogram of residuals

Jarque-Bera Test

To check the model residuals for the normality of the distribution, the Jarque-Bera test was conducted, which confirmed the hypothesis of the normality of the distribution of the model residuals. The resultant *p*-value of 0,1377 indicates that for α=0.05 or even α=0.1 the null hyphotesis asserting normality cannot be rejected. It should be noted that the Jarque-Bera test often rejects this hypothesis for large data samples, detecting even minor deviations from a normal distribution.

The constructed regression equation has the form:

$$\log\_bonds\_value = -9.8343 + 0.1436 credit\_rating + 1.5\log\_GDP\_per\_capita + 0{,}8\log\_population$$

$\log\_bonds\_value$ – logarithm of the volume of "green" bond issuance;

$credit\_rating$ – rating assessment of the creditworthiness of the issuer's country of residence on an ordinal scale;

$\log\_GDP\_per\_capita$ – the logarithm of the GDP of the issuer's country of residence per capita at purchasing power parity;

$\log\_population$ – the logarithm of the country's population.

The estimated regression parameters indicate that a one-unit increase in the credit rating of the issuer's country of residence in the ordinal scale leads to a 14.36% increase in the volume of "green" bond issuance. A 1% increase in GDP per capita leads to a 1.5% increase in the volume of green bond issuance. A 1% increase in the total number of the country's population, in turn, leads to an increase in the volume of issuance of "green" bonds by 0.8%.

V. CONCLUSIONS

The obtained results showed that the rating assessment of the creditworthiness of the issuer's country of residence significantly affects the market of "green" bonds. Green bonds are a new financial instrument, and it is difficult for investors to assess the potential risks, so they rely on ratings. Investors use the credit rating as a tool for

assessing the issuer's default risk. To gain access to the financial market for financing environmentally friendly projects, the issuer needs a good rating. Therefore, the state should encourage issuers to receive ratings (bond rating, issuer rating, etc.). This will increase the demand for "green" bonds, which investors would perceive as a safe financial instrument.

According to the built model, the increase in the population has a positive effect on the level of emission of "green" bonds. This is consistent with the findings of [29], where the volume of bond issuance also increases with the population. This result can be explained by the fact that ecologically clean projects improve the quality of life of the population, and the growth of the population requires reliable and affordable "green" financing for ecologically clean projects.

Our research confirmed that the economic development of the country, characterized by GDP per capita, and the development of the "green" bond market go hand in hand.

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THE RELATIONSHIP BETWEEN THE FACTORS THAT FORM STUDENTS' LOYALTY TO THE UNIVERSITY

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Abstract. *The key objectives of this study were to study the links between the perceived value of students, the image of the university and student satisfaction with student loyalty and to describe the relationship between the influence of intermediary variables in the student loyalty model. The model was tested using the methodology of finding the average value of loyalty. Empirical data were obtained from 100 students from five top universities in Kazakhstan. During the collection of information with an error of 1%, the questionnaire method and multi-stage sampling methods were used. Data analysis with descriptive statistics was used to test the hypothesis of the model. The results of this study showed that student satisfaction and two other variables: the image of the university and the perceived value of students have a positive impact on student loyalty. Moreover, the results also show that the perceived value of students was what most affects the image of the university, and strongly indirectly affects student satisfaction. The influence of perceived value also has a connection of student loyalty through student satisfaction. The main issue is the influence of the student satisfaction variable, which has the greatest direct impact and conveys the relationship of relative influence between the preceding variables and the dependent variable. In conclusion, student satisfaction was a mediating variable, and this implied that student satisfaction was a major factor in student loyalty.*

Keywords: *Student loyalty, Student satisfaction, University Image, Student Perceived Value, Commitment.*

I. INTRODUCTION

Currently, there is a sharp leap in the world in the field of higher education. This is explained by a multi-level system and the need for narrow knowledge in certain areas. As of 2023, there are 128 universities in Kazakhstan, and for example in Ukraine, their number has already reached 657. The most interesting thing is that the need for education will only grow; therefore, the number of universities will increase.

Consequently, competition is becoming more and more intense in the market among universities. Attracting and retaining students can help higher education administrator's better make decisions regarding the allocation of limited resources [1]. Therefore, understanding student retention and student satisfaction should be the most important issues to determine the most appropriate strategicmanagement to ensure the long-term success of both public and private institutions.

Based on the literature review data, it is emphasized that student satisfaction was the dominant variable for student loyalty, and both of them interact positively. In short, this means that when students were satisfied with the university, they showed a positive attitude and behavior towards the educational institution.

It was clear and expressed by word of mouth and fashionable words about the good reputation of the university, which was a positive indicator that students would continue their studies at the university. The most important task is to increase student satisfaction and loyalty, especially for private educational institutions [2].

Several reasons for student loyalty have been found as a key goal that many higher education institutions strive for, including :

1) Tuition money is the main source of income for most private universities. Retaining students means creating a strong and a predictable financial basis for the future activities of the university.

2) The theory of marketing services based on the participation of buyers, indicates that a student who is loyal to his educational institution can positively influence the quality of teaching through active participation and interested behavior.

3) After graduation, a student who shows loyalty can continue to support his/her educational institution(s) financially; (b) by distributing information to other potential, current or former students; and (c) through some form of cooperation.

As mentioned above, it is shown that high competition in private higher education would greatly affect the stability of private higher education institutions, which prompted and provoked the researcher's interest in conducting this study. In this regard, the purpose of this study was to find a correlation and attachment between four latent variables, namely: student loyalty, student satisfaction, university image, and perceived value of students. Using simulation of multi-stage random sampling to find the interrelationships and influences of the preceding variables on student loyalty, and also examines the influence of student satisfaction as a constraining variable that mediates the relationship linking the perceived value of the institution, the image of the institution with student loyalty.

II. LITERATURE ANALYSIS

2.1. Customer loyalty

Loyalty in the field of education is becoming one of the priority factors for the growth of competitive advantage and, therefore, it is necessary to direct efforts to create and retain competitive advantages based on loyalty to the educational services provided in this institution. Loyalty reflects loyalty to the goals, ideas and values of the institution, the direction of its activities.

Competitiveness of educational institutions is given by such aspects of the organization as popularity, prestige, and demand for graduates in the labor market after graduation from an educational institution, compliance of the training of graduates with modern requirements of the economy and society and the conditions of globalization of the educational space. Factors such as a sense of the importance of learning, the friendly attitude of the management, the developed technological and household infrastructure of the institution, confidence in the positive prospects of their future employment play an important role for the student.

Customer loyalty still attracts the attention of scientists because of its deserved importance. Consequently, this term has a wide range of meanings. For example, R.

Oliver believed that loyalty is a stable purchase of goods or services from the same brand, despite the presence of various obstacles and competitors in the market [3].

Jiang and Zhang, on the contrary, defined loyalty as an intangible emotional connection between a company and customers. This sympathy and connection make people purchase goods and services [4].

Customer loyalty can also be classified by type. Candampulli believed there are two types of customer loyalty: a) active loyalty and b) passive loyalty. The company can have active and passive loyal customers. Both types are valuable, but active loyalty has become more important due to the widespread use of the Internet and social networks [5].

Unlike Candampulli, Dick and Basu divided customer loyalty into 4 types based on two dimensions of relative attitude and constant patronage; these types or groups include, namely: a) lack of loyalty, b) loyalty, c) hidden loyalty and d) false loyalty. Marketing specialists and companies should take this kind of loyalty into account in their research because of its important impact and consequences [6]. Recognizing these concepts allows to delve into the topics of loyalty in the field of higher education.

2.2. Student Loyalty

After analyzing the definitions from the literature of Helgesen & Neseti and Thomas, it can be concluded that student loyalty refers to the loyalty of a student after his or her stay at an educational institution [7]. This type of loyalty has both a short-term and long-term impact on the educational institution.

According to Henning-Turau, the student loyalty is a mixture between the willingness of students to express positive feedback about an educational institution and recommendations about an educational institution to family, friends, relatives and companies at any opportunity [8].

Students who show loyalty have a positive impact on the quality of teaching through active participation and purposeful behavior. Rodie and Klien substantiated this idea in their writings [9].

Consequently, university administrators, by maintaining long-term loyalty and student satisfaction, directly increase the stability of academic institutions. So loyal students are ready to pay tuition fees, participate in scientific activities and recommend an educational institution to friends and relatives.

According to Kend, perceived quality of service and student commitment are the main factors driving student loyalty [10]. The quality of service, trust and emotional commitment are consistently positive, strong and meaningful.

Helgesen Eyvind and Nesset Erik attentivly studied the relationship between the quality of service, amenities, student satisfaction, image and student loyalty.They reported that satisfaction directly affects loyalty [11].

Rojas-Mendes et al. reported that students' trust and satisfaction have some indirect effect on loyalty. The authors established relationships in the following direct order: perceived quality of service, satisfaction, trust and commitment [12].

Orozco Encinas and Cavazos Arroyo also reported that the loyalty of graduate students to their alma mater can be explained by commitment and participation in the joint creation of the service [13].

2.3. Student Satisfaction

Satisfaction is the general attitude of a customer to a supplier's service or an emotional reaction to the difference between what customers expect and what they receive, in this case in relation to meeting some needs, goals or desires. The importance of meeting the needs of students for their retention in commercial institutions meeting the needs of accepted students is also important for retention. It could be argued that dissatisfied students can reduce the number of courses or drop out of college completely. Consequently, the student's satisfaction or dissatisfaction leads to the intention to stay or quit, which in turn leads to the retention or retirement of students according to Kara and De Shields [14].

Moreover, according to Douglas, there is a positive correlation and a significantly strong effect between student satisfaction and their loyalty. It was also found that where students have a choice, the relationship between satisfaction and loyalty is linear, as satisfaction increases, loyalty also increases [15].

Hypothesis 1: Student Satisfaction has a linearly equal positive effect on Student Loyalty to an educational institution

2.4. University Image

An image is a complex impression that a person has about an object. It is based on partial information and differs from various institutions, a definition according to Kotler and Fox [16].

Gronroos found that Image influences consumers' perception of companies' communications and operations in many aspects [17]. These aspects include communication between students, in other words, word of mouth.

Organizations would be considered to have a good image if customers believed that they could receive benefits or interests from organizations. A favorable corporate image of a firm can be useful in a competitive market, as it can distinguish a firm from its competitors. A good image elevates the organization above its competitors and stops the buyer's choice on itself.

Alves & Raposo emphasized in their works that image always acts as one of the variables that have the greatest direct impact on satisfaction, and also has a significant impact on loyalty [18].

According to literature reviews by Mohamad and Brown & Mazzarol, it was found that the image of the university directly and positively affects the loyalty of students. They also found that the effect of student satisfaction significantly mediates the relationship between the image of the university and the loyalty of students [19].

Nevertheless, the image is the one that has the greatest impact on the process of satisfaction formation, but there are other prerequisites that affect the image of the university and the consequences of student satisfaction. Here the following hypothesis is formed:

Hypothesis 2: The image of the university has a clear positive impact on student satisfaction

2.4. Perceived value of the student

Perceived value is defined as the final assessment by the buyer of the usefulness of a product or service based on the perception of what is received and what is given, deffenition according to Zeithaml [20].

At a University or Institute, a student's overall assessment of the net value of a service is based on the student's assessment of what is received (benefits provided by the service) and what is given (costs or sacrifices in acquiring and using the service). Meanwhile, the student's general perception of the value of service has a positive effect on the student's satisfaction with the service.

According to a literature review by Andersen & Lindestead, it becomes clear that perceived value has been identified as a satisfaction factor. As for the relationship between perceived value and satisfaction, it was discovered that the perceived value of a student directly and significantly affects student satisfaction, but does not have a significant and direct effect on student loyalty. Moreover, these scientists found out that the value perceived by students directly affects student loyalty through student satisfaction [21].

However, the perceived value of students also has a related impact on the image of the university and the trust of students. As already mentioned, it examined the indirect causal relationships between the perceived value of students and the loyalty of students, which was mediated by student satisfaction, in addition to studying the direct relationship between student trust and the image of the university. Thus, the following hypothesis was formulated:

Hypothesis 3: The perceived value of a student has a direct impact on the image of the university

Hypothesis 4: According Hypothesis 3 perceived value indirectly, but significantly affects student's satisfaction, through university image.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

3.1. Population and Samples

The object of this study were students of 1-5 courses of private higher educational institutions in Kazakhstan, the city of Almaty.

The subject of this study is assessment of various factors and the relationship between them on the loyalty of students to higher education institutions

The students in the research sample were recruited from full-time students. The study involved students from the following universities: the International Information Technology University (IITU), the Kazakhstan Institute of Management, Economics and Strategic Research(KIMEP), the Kazakh-British Technical University (KBTU), the Kazakh National Medical University KazNMU, and the Kazakh-Russian Medical University (KRMU).

When collecting data, *the method of multi-stage random sampling* was used with an error of 1% in the sample size. Multi-stage sampling gives researchers with limited means and time a method of sampling from such populations. This sampling procedure

is essentially a way to reduce the population by dividing it into smaller groups, which can then be the subject of random sampling. As long as the groups have low intergroup variance, this form of sampling is a legitimate way to simplify the population. The multi-stage sampling form is flexible in many senses. First, it allows researchers to use random sampling or cluster sampling after defining groups. Secondly, researchers use multi-stage sampling indefinitely to divide groups and subgroups into smaller groups until the researcher reaches the desired type or size of the group.

The total sample consists of 100 students; 69 women and 31 men, with an effective response rate of 100%. Of the respondents, 48% are IITU students, 22% are KazNMU students, 13% are KRMU students, 10% are KIMEP students, and 7% are KBTU students.

3.2. Measure of concepts

This research was quantitative and used the construction in the model of Thomas, Mohamed and Helgesen and Nesset. Usually this model is used to display links. In economics, it is needed for grouping between variables. The advantages of this model are data integrity, clarity of information location and convenience in graphical display. The model has been redesigned both latent and explicit variables according to the environment and culture of the population to be studied.

The average amount modeling approach was used to test the model. Advantages of average amount modeling approach:

- Works great for aggregates whose values add up easily;
- Simply calculated: fold, divide and conquer;
- Intuitively, the arithmetic mean for us is just a "number somewhere in the middle" between the largest and smallest value.
- Perfect for comparing individual groups.

Therefore, this procedure allowed to fully testing the proposed model structure. Each design was covered by a set of several questionnaire items.

The questions concerned were a questionnaire requesting information about constructs of four latent variables that include student loyalty, student satisfaction, university image, and perceived value of students.

Table 1. Answer options in the questionnaire

Student satisfaction	**Student loyalty**
Very dissatisfied	Very dissatisfied
Dissatisfied	Dissatisfied
Neither dissatisfied or satisfied	Neither dissatisfied or satisfied
Satisfied	Satisfied
Very satisfied	Very satisfied
University image	**Perceived value of students**
Very dissatisfied	Very dissatisfied
Dissatisfied	Dissatisfied

Neither dissatisfied or satisfied	Neither dissatisfied or satisfied
Satisfied	Satisfied
Very satisfied	Very satisfied

To measure independent and dependent variables, the Liberty data format was used in the form of an ordinal number in order to use descriptive statistics to summarize data collected in simple numerical form. In the measurement model, 8 indicators were used to measure the study of hidden constructs; student loyalty (2 indicators) student satisfaction (2 indicators) and the image of the university (2 indicators) and the student's perception of value (2 indicators)

IV. RESULTS

4.1. Analysis of the results of the student survey

For ease of analysis, the components in the table below have been divided into several sections and calculated for each university from which the students were interviewed. The loyalty section includes commitment and frequency of recommendations. In the satisfaction section, there was satisfaction with educational programs and teaching staff. In the image of the university, there were questions about the availability of grants and the recognition of the educational institution. Finally, in the "Perceived value section" there was help for students with work, a place of practice and events held for them.

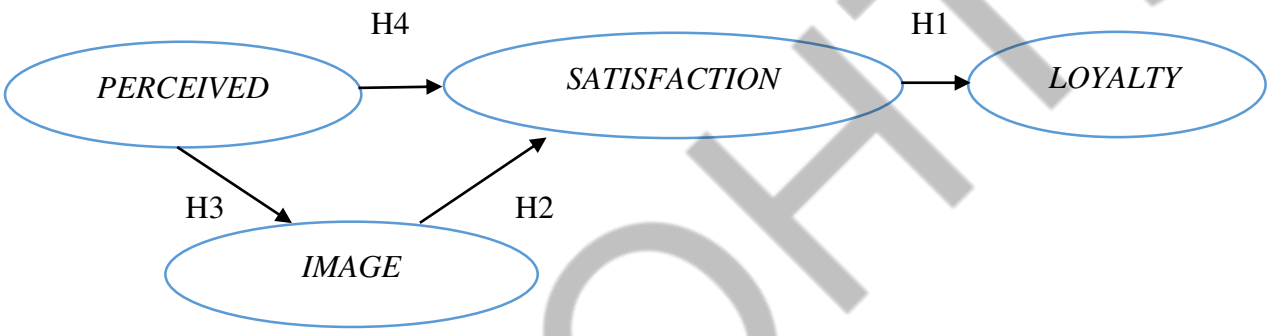
Table 2. Loyalty level results of five universities

Latent Variable	**Indicators**	**IITU**	**KazNMU**	**KRMU**	**KIMEP**	**KBTU**
Student loyalty	Commitment	2.7	2.6	2.4	2.5	2.3
	Recommendations	2.8	2.6	2.3	2.5	2.3
Student satisfaction	Satisfaction with the teaching staff	2.7	2.4	2.4	2.5	2.4
	Satisfaction with the edu program	2.6	2.5	2.4	2.6	2.4
University Image	Availability of grants (for research)	2.5	2.0	2.3	2.5	2.5
	Recognition	2.5	2.6	2.3	2.6	2.4
Perceived value	Help from the university (place of practice)	2.5	2.9	2.8	2.7	2.3
	Availability of educational activities	2.8	2.2	2.3	2.6	2.5
Average		2,7	2,5	2,4	2,6	2,4
Note. Prepared by the auther based on the survey						

According to the survey, the attitude of students to the university was calculated by identifying the average value of the numbers assigned to the components. IITU University received the highest loyalty, KBTU and KRMU received the lowest. During the calculation of the data, a certain sequence and explanation of the answers in different categories were revealed.

4.1. Testing the Hypotheses

The figure below represents a certain relationship between the latent components. The results of the students' responses confirmed the hypotheses put forward earlier. More precisely, that satisfaction affects loyalty. Moreover, the satisfaction itself falls under the power of the image of the university, which is formed under the influence of the perceived value of students.



Note. Prepared by the auther based on the survey

Figure 1. Latent Variables Relations Model

As evidence, the study can give data about IITU and KRMU. The overall loyalty index in IITU was 2.7 in KRMU 2.4. As a result, the components of the Perceived value of IITU are higher than in KRMU. Consequently, such indicators as "Image of the university", "Satisfaction" and "Loyalty" are also higher at IITU. That is, the perceived value determines the low or high value of the remaining elements. This means that the figure above and all the hypotheses formed above are proven.

4.2. Proof of the hypothesis on the example of IITU

IITU takes care of the precived value by the student. To do this, the following management actions are carried out at the university:

- The university has a career center. Here, students are offered vacancies for employment after graduation. Students can also looking for a place to practice in this center while studying.
- There are a large number of student organizations where students can practice hobbies and find friends with common interests.
- The university also hosts many events at the level of the city and the republic. For example, the Miss IITU beauty contest. The finalists of this contest often participate in Miss cities, even going to the Miss Kazakhstan contest. Also at this university, a winter ball, dedication (where famous bands perform) and

many other events are held.

Since students have received value from the university, they are motivated for scientific activity and win prizes in competitions. Which greatly enhances the image of the university. For example, students of this university often take prizes in the YDF, in republican Olympiads and many other competitions. There is also an innovation center at the university. Innovation center of IITU released many projects that have gone on sale at the country level or have benefited free. Examples of these projects:

- Tazalyk is an application that allows you to establish communication between producers and recipients of garbage. Tazalyk solution: all recycling collection points are marked on the map; The opportunity to earn bonuses by handing over garbage to collection points and exchange bonuses for valuable prizes and services.
- GLUCOMED is a mobile application for monitoring blood sugar levels. The functionality includes: blood sugar level determination, self-monitoring diary, carbohydrate value database of products, insulin bolus calculator, structured data export
- Ui januarlary - The book will give children the opportunity to study pets using a mobile application with AR technologies.
- Sound accompaniment and visual effects will help the child to develop memory and associative perception of animals much faster.
- The book is completely in three languages: Kazakh (Latin), Russian and English.
- Boshon - Educational courses on robotics for schoolchildren and students within the framework of the project "School of Robotics Boshon IT School MUIT"
- OkuPlus is an online educational platform, training in IT professions.
- Baursak is a mobile game for children that teaches children the Kazakh language.
- Jaqsy is a charity cashback service.

At IITU, the students receive beneficial value from the university and study in a prestigious place at a university with a good image. Therefore, they feel better than their peers do. So they become satisfied. Moreover, satisfaction is almost synonymous with loyalty

So, going through the reverse order of hypotheses, it can be considered proven that loyalty depends on satisfaction, and satisfaction depends on the image of the university and precived value by the studends.

V. CONCLUSIONS

The analysis of scientific literature devoted to the search for factors forming student loyalty and the links between them is reduced to several main components. First, loyalty depends on satisfaction. Satisfaction is based on the image of the university. The image of the university depends on the third last component – precived value of students. Based on these data of the literature review, theories about the relationship of these components are formed.

In the practical part of the research work, a survey was conducted among

students of five top universities in Kazakhstan. The questions were created based on an average sum modeling approach. After evaluation and counting, the results were grouped according to the model of Thomas, Mohammed, Helgesen and Nesset. All latent variables were placed in the table and each was assigned its own value according to the results.

The results of the study showed that IITU students are the most loyal, because their average value of latent variables turned out to be higher than that of other universities. In terms of testing hypotheses, it turned out that the university system is just the same adjusted to model of Thomas, Mohammed, Helgesen and Nesset. The evidence were:

- Maintaining precived value of students through employment and themed clubs and events
- Directing gratitude from perceived value to motivate students to scientific activity and victories in this field. Thereby raising the image of the university.
- The image of the university, in turn, affects the attraction of qualified teaching staff and the availability of competitive educational programs. The last two points have a very strong effect on student satisfaction, which directly affects loyalty.

Thus, the hypotheses put forward at the beginning of the study about the relationship between loyalty, satisfaction and the image of the university and the precived value were confirmed. The order of these components was also confirmed, for the greatest efficiency

In conclusion, study suggests some specific areas for improving higher education institutions, based on the examples of IITU University to create satisfaction among students. To counter this, institutions must recognize student retention activities by initiating institutional student satisfaction. These can be a variety of activities, depending on the background, institutional nature, location, as well as institutional philosophy.

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ORGANIZATION OF ACCOUNTING FOR THE MANAGEMENT OF COSTS FOR THE PRODUCTION OF ORGANIC FOOD PRODUCTS: GLOBAL EXPERIENCE AND PRACTICE OF UKRAINE

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Annotation. *The study is devoted to the study of the state of the organization and accounting methods of organic production costs from the point of view of ecological and economic accounting in Ukraine and providing recommendations on the adaptation of accounting support for the management of costs of organic production to the requirements of the formation of integrated information of ecological and economic accounting.*

In the absence of regulatory accounting regulation in Ukraine in the conditions of organic production, the formation of internal normative accounting regulations is a necessary condition for effective management of such production. A system of cost accounting objects has been created, which considers the specifics of the technological processes of operators of organic production and will allow to organize separate accounting of costs to produce organic products, inorganic products, and products of the transition period. A nomenclature of cost accounting articles in the conditions of organic production is proposed, the application of which will make it possible to distinguish in accounting the costs allowed by the legislation in the conditions of organic production, from costs for which there are certain restrictions. Features of the functions of primary documents reflecting the costs of organic production are determined and ways to improve the documentation of production processes are proposed. This will improve the information support for product quality control and will allow adapting the accounting support for the management of production costs of organic products to the requirements of the formation of integrated information of environmental and economic accounting.

Keywords*: ecological and economic accounting, management, costs, organic production, management information support.*

I INTRODUCTION

The development of organic production in Ukraine began in the late 1990s. Before the full-scale military invasion, Ukraine was actively advancing on the international market of organic products and developing the domestic market. In recent years, our country has become one of the world leaders in terms of the area of agricultural land used for growing organic products and the variety of such products.

The fast-moving development of organic production in Ukraine and the world is a response to the desire and growing capabilities of the population in consuming healthy food products and public awareness of the real threat and harm of industrial agriculture due to negative environmental, social and economic consequences. Organic agriculture is one of the key factors in solving global environmental and social problems and in achieving the goals of sustainable development. Therefore, the number of people interested in receiving information about the state of development of organic

production, its real costs, the cost of organic products, etc., is growing. Organic agriculture can be a pathway to addressing not only hunger and malnutrition but also other challenges including poverty, water use, climate change, and unsustainable production and consumption [1]. More than 800 million people go hungry and about 2 billion are malnourished. About 30 percent of the global adult population is overweight or obese, and around 30 percent of food produced worldwide is lost or wasted.

Nature is declining globally at rates unprecedented in human history. Up to 1 million species are threatened with extinction, many within decades.

Land degradation has reduced the productivity of 23% of the global land surface; up to US$577 billion in annual global crops are at risk from pollinator loss.

The modern system of accounting for income and expenses is far from perfect. It contains a lot of approximations, assumptions, and unaccounted factors. The accounting system of Ukraine and international accounting practice do not consider in the price of produced products those costs and benefits that arise as a result of the impact of the activities of business entities on the eco-agri-food system, on the life of society in general. call it an "external effect" [2]. The authors interpret the external effect as positive or negative consequences of the subject's activity that affect others, while not being reflected in the price of goods or services. In terms of costs, these are those that will be incurred for the restoration of soils, the restoration of disturbed ecological systems, the costs of end users of low-quality products for the maintenance and restoration of health, etc. Domestic and international practice provides cost accounting only in the "visible range" by analogy with the tip of the iceberg. Using the current methodology, we cannot, for example, realistically compare the costs and benefits of the production of organic and inorganic products, because accounting provides limited information. The same, even to a greater extent, can be noted about statistical data, as an accounting system that provides information at the macro level. All this makes it impossible to effectively manage the costs of food production and consumption and leads to the emergence and deepening of problems of a global scale.

II. ANALYTICAL REVIEW OF LITERATURE

Scientists draw attention to the fact that society, consuming low-quality, cheap food products, does not consider the significant costs that it bears or will bear in the future. And these unaccounted costs are borne not by the product manufacturer, but by the global community. Thus, Barbara Hammill-Herren, Lauren E. Baker, and Paul A. Daniels note that behind all the food we consume, a huge number of unaccounted-for negative consequences are hidden: shallowing of rivers; removal of nutrients from the soil; discharge of pollutants into the air and water; labor force exploitation; carbon dioxide emissions and so on [3].

In the world accounting practice, attempts are made to consider the costs of the interaction of economic activity and the eco-agro-food system. Thus, in 1993, the "System of National Accounts" was adopted, which introduced the concept of integrated environmental and economic accounting [4]. In 2012, the Statistical Commission of the United Nations adopted the "Central Basis of the System of Natural and Economic Accounting" [5] as an international statistical standard.

The work of Ukrainian researchers, in particular H. Kaletnik, S. Lutkovska, is dedicated to the study of the problems of ecologically oriented activity of the agrarian

sector of the economy. The authors propose various forms of public-private partnership to solve urgent problems of environmental and economic security. One of these ways is state support for organic production [6].

The study of the current state of the organization and methods of accounting for the costs of organic production from the point of view of ecological and economic accounting in Ukraine was carried out by Y. Ishchenko [7].

III. OBJECT, SUBJECT AND METHODS OF RESEARCH

The object of the study is the accounting system of costs to produce organic products from the point of view of ecological and economic accounting in Ukraine.

The subject of the study is a set of theoretical, organizational, and methodical principles of accounting.

The methodological basis of the research is general scientific and specific methods.

Among the general scientific methods should be mentioned the system method. Systematic research makes it possible to fully cover and track the process of organic production; its qualitative characteristics; changes that occur at each stage of development. The system approach makes it possible to analyze organic production from the standpoint of integrity and interconnection of the main elements, their impact on the environment.

The general dialectical approach is crucial for the methodology of research of organic production. Its application allows us to recognize the contradictions between industrial agriculture and organic production, between traditional economic interests and the environmental imperative.

The combination of dialectical and systemic approaches to the knowledge of phenomena and processes has made it possible to outline trends in the development of ecological and economic accounting in the context of organic production.

Methods of induction and deduction, monographic method, method of theoretical generalization and comparison and method of concretization were used to reveal and deepen the essence and identification of objects of accounting of organic production.

The methodological principles of accounting were studied using a questionnaire, a graphical method, and a method of causation. Methods of extrapolation and analogy served to determine the directions of development of domestic accounting of organic production, considering international experience.

Induction and deduction methods were used to determine the general trends in the development of accounting for the costs of organic production. Methods of theoretical generalization and comparison are used to reveal the nature and content of the costs of organic production and organic products as economic categories and objects of accounting. Economic and statistical methods were used to analyze the state of organic production, and the method of observation - to study the state of accounting support for cost management of organic agricultural production.

IV. WORK RESULTS

According to the International Federation of the Organic Agricultural Movement (IFOAM), organic agriculture is a holistic production system that preserves soils, ecosystems, food and nutrition. Such a system is designed to create conditions that support environmentally, socially and economically feasible agricultural production [8].

In recent years, there has been a positive global trend for all key indicators of organic production. The area of agricultural land with organic status increased from 11 million hectares in 1999 to 72.3 million hectares in 2019. 200,000 operators of organic production were registered worldwide in 1999. Their number was already more than three million in 2019. The organic market grew from € 15.1 billion in 1999 to € 106.4 billion in 2019 [10].

According to IFOAM, Europe has the largest share of countries where organic farming is cultivated (Table 1). Ukraine is also among them.

Table 1

Number and share of countries (by regions) that conducted organic production, 2019

Region	Number of countries with organic farming	Number of countries in the region	Share of countries producing organic products, %
Africa	47	61	77
Asia	42	51	82
Europe	48	51	94
Latin America and the Caribbean	33	48	69
North America	3	4	75
Oceania	14	24	54
World	187	239	78

Source: [9, 10]

As of the beginning of 2020, 16.5 million hectares of agricultural land (about 3.3% of the total area) were used for organic production in Europe, which is almost 6% more than the level of 2019 (Fig. 1), operated over 430 thousand operators of organic production (Figure 1) [12].

The largest areas under European production in Europe are in Spain (2.35 million hectares), France (2.24 million hectares), and Italy (1.99 million hectares). The top 3 European countries in terms of the share of organic land are Liechtenstein (41.0%), Austria (26.1%) and Estonia (22.3%). Sales of organic products by European countries in 2019 amounted to 45 billion euros, which is 8% more than last year. The leaders in retail sales of organic products among European countries are Germany (12.0 billion euros), France (11.3 billion euros) and Italy (3.6 billion euros).

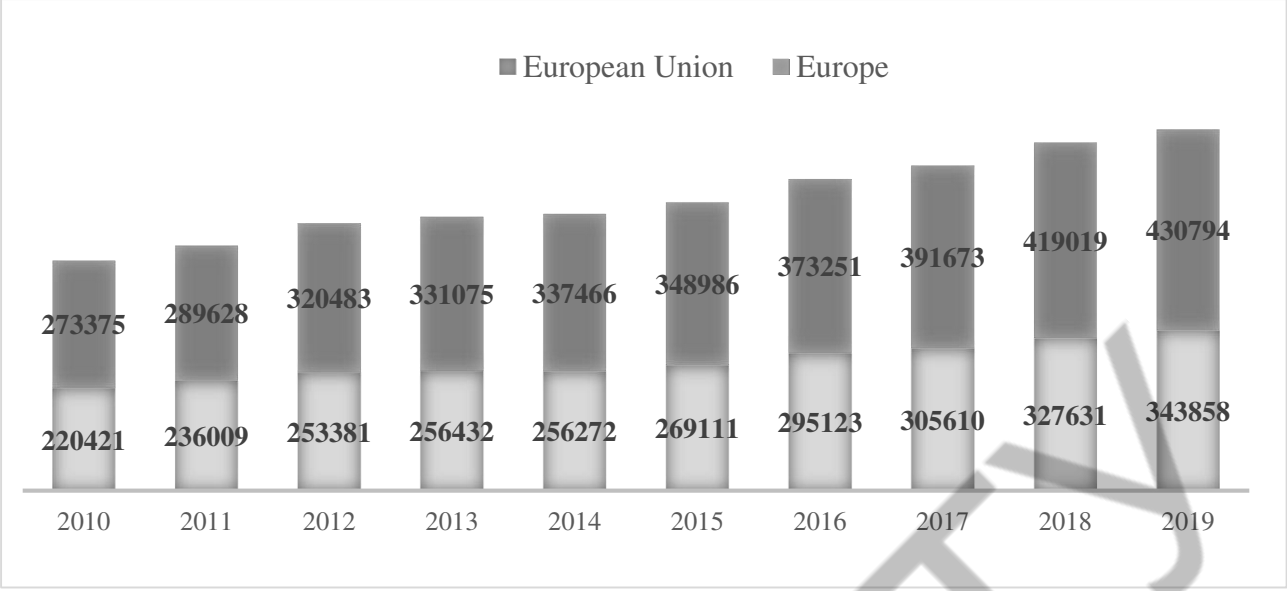

Figure 1. Dynamics of the number of producers of organic products in Europe
Source: [12]

And although Ukraine is not one of the leading countries in terms of area or production of organic products, in 2019 it took second place among European countries in terms of growth rates of areas involved in organic production (Figure 2). According to the growth of the market of organic products in 2019, Ukraine entered the top 10 European countries and took eighth place (Figure 3).

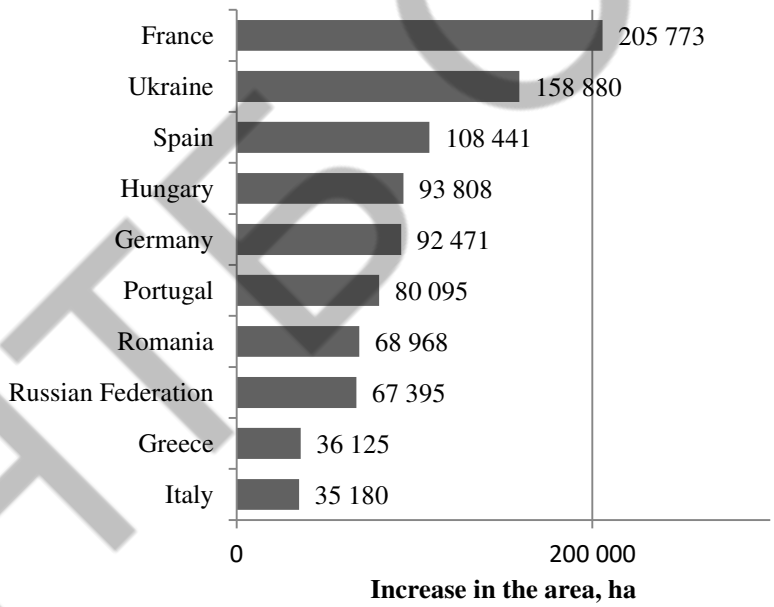

Figure 2: Leading countries with the highest growth of organic agricultural land in 2019, ha
Source: [12]

Ukraine continues to accelerate the development of organic production and according to experts is a promising country for significant expansion of the organic market in Europe.

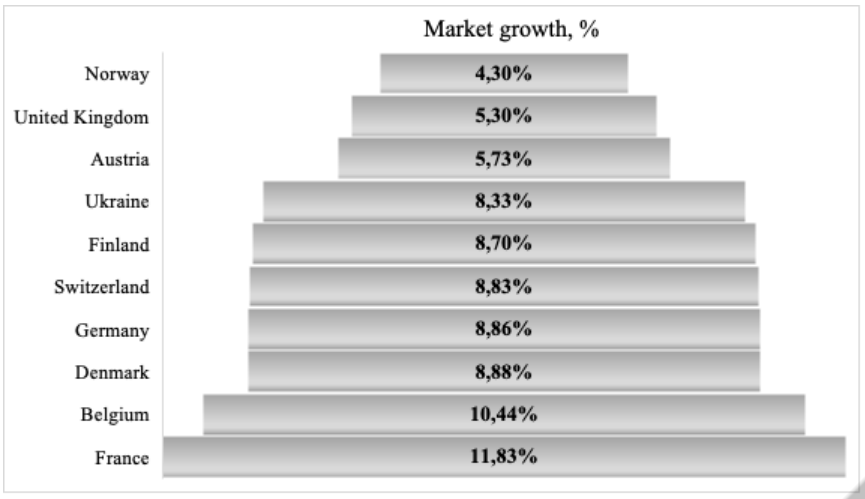

Figure 3. European countries with the highest growth of the organic market in 2018-2019

Source: [12]

Thus, organic agricultural production in Ukraine is one of the priority areas of development of the agricultural sector of the economy, in accordance with the adopted National Economic Strategy for the period up to 2030 [15]. Accordingly, the priority ways of achieving the strategic goals of the state regarding the development of the agro-industrial sector are the following (Figure 4).

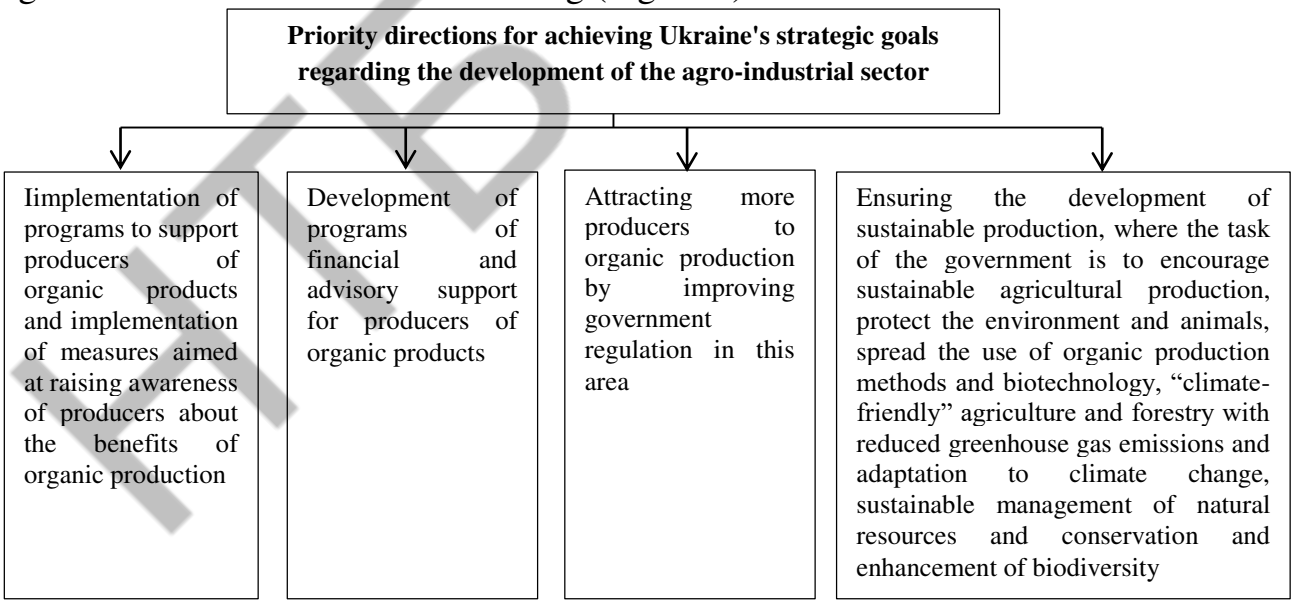

Figure 4. Priority directions for achieving Ukraine's strategic goals regarding the development of the agro-industrial sector

Source: [15]

The key indicators that characterize the development of organic production in Ukraine are presented in Table 3.

Table 3

Dynamics of organic production development in Ukraine

Indexes	Years						from 2020 to 2015,%
	2015	2016	2017	2018	2019	2020	
Number of operators of organic production, units	210	360	375	510	617	549	261
Total area of agricultural land with organic status and transition period, thousand hectares	410,55	411,20	420,00	429,10	467,98	469,22	114
Volumes of the domestic consumer market of organic products, million euro	17,5	21,2	29,4	33,0	36,0	38,2	218

Source: [13]

Most of the organic products produced in Ukraine are imported to European countries. The top 10 importers of Ukrainian organic products in the EU are presented in the table. 4.

Table 4

Top 10 importing countries of Ukrainian organic products in the EU, 2020

№	Country	Volume, tone	Cost, million dollars USA
1	2	3	4
1	Netherlands	97400	29,5
2	Germany	41800	27,0
3	Lithuania	21500	5,8
4	Austria	18600	15,8
5	Poland	15300	19,6
6	Italy	6500	4,0
7	Romania	4800	3,0
8	Spain	3500	1,7
9	Czech Republic	2800	3,0
10	Belgium	2600	1,3
	In total	217000	116,7

Source: [14]

Organic production as a holistic production system that contributes to environmental and food security, reducing anthropogenic pressure on nature, rational use of natural resources, environmental protection, creating sustainable systems of agricultural production and food processing. This, in turn, minimizes society's costs associated with food production and consumption and increases producer costs.

Thus, the main task of accounting in organic production is the formation of an accounting system that would provide information requests to stakeholders about the costs of organic food producers. After all, at the micro level, in terms of organic production, environmental and economic accounting is an information system that

allows you to monitor compliance with domestic and international legislation for this type of activity, and, in the following stages, to form consistent and comparable statistics to consider relationships between the environment and the economy. Today in Ukraine there is a lack of information to meet the needs and requests of stakeholders about the state of development of organic production, the cost of production of organic products, its cost, and so on. For effective management of such production at both micro and macro levels, it is essential to provide reliable and complete coverage in management, financial and statistical reporting of information on the costs of production of organic products.

Ukrainian legislation in the field of organic production is currently being formed. The basic normative act that determines the legal, economic, and social bases of organic agricultural production in Ukraine is the Law of Ukraine "On production and circulation of organic agricultural products and raw materials" from 03.09.2013, No. 425-VII. This Law defines the legal and economic basis for the production and circulation of organic agricultural products and raw materials and aims to ensure the proper functioning of the market of organic products and raw materials, as well as to ensure consumer confidence in products and raw materials labelled as organic [17].

The main requirements for organic production are determined by the Law of Ukraine "On Basic Principles and Requirements for Organic Production, Circulation and Labelling of Organic Products" dated July 10, 2018, No. 2496-VIII. This normative act defines organic production as a certified activity related to the production of agricultural products, including all stages of the technological process, namely primary production (including harvesting), preparation, processing, mixing and related procedures, filling, packaging, processing, recovery and other changes in the state of production), which is carried out in compliance with the requirements of legislation in the field of organic production, circulation and labelling of organic products [18].

The general requirements for organic production determine the need to separate in time or space the production and storage of organic products, including accounting for such products, from the production and storage of inorganic products and products of the transition period [18]. That is, at the legislative level, operators of organic production are required to organize separate accounting of costs of production of organic, inorganic products and products of the transition period, which must be considered when building a system of cost accounting facilities.

The organization of production cost accounting is a complex process that includes determining the list of production cost items and their composition; cost accounting objects and calculation objects; the structure of sub-accounts and analytical accounts of direct and indirect costs of production; the procedure for displaying expenses on invoices and methods of including expenses in the cost of each costing object; selection of methods of evaluation and accounting of finished products (main, secondary, secondary), accounting of future costs; development of methods and methods of accounting for production costs and forms of internal reporting on costs and output. In addition, in the conditions of organic production, accounting should be organized by its branches, which include the following (Figure 5).

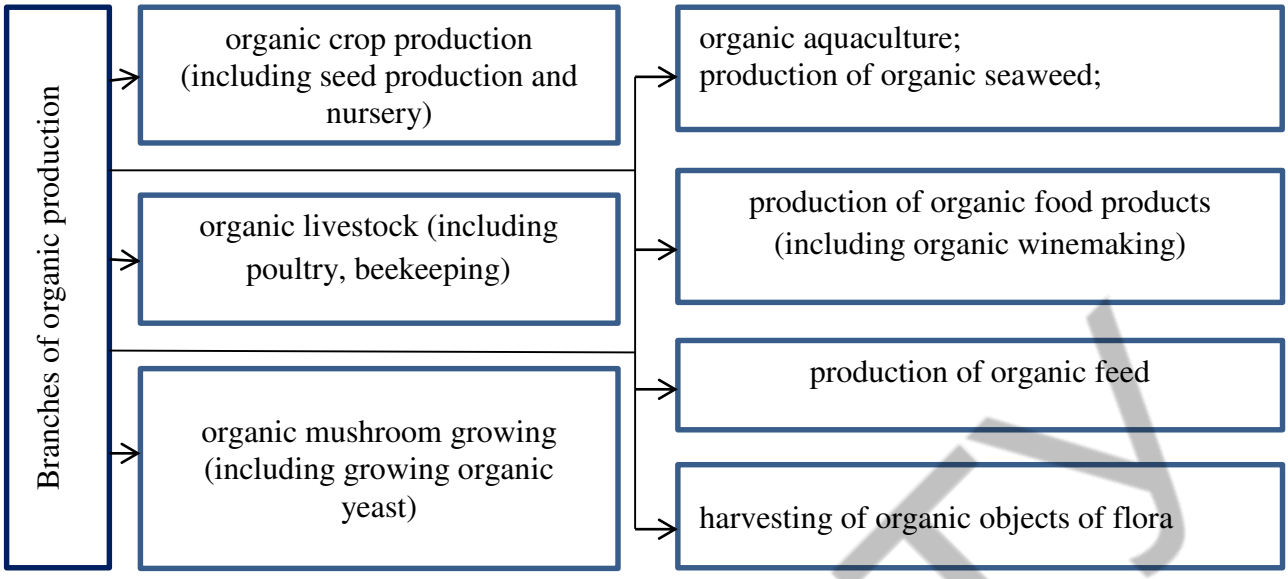

Figure 5. Branches of organic production
Source: [18]

The objects of cost accounting in agricultural production are traditionally crops (groups of crops), species and groups of animals. However, due to the specifics of technological processes of operators of organic production, the construction of a system of cost accounting facilities for such entities will be somewhat more difficult (Figure 6).

OBJECTS OF ACCOUNTING COSTS OF ENTITIES - OPERATORS OF ORGANIC AGRICULTURAL PRODUCTION		
Production costs of inorganic products	**Costs of transition period**	**Costs of production of organic products**
- industries; - production units; - cultures (groups of cultures), species and groups of animals.	- branches of organic production; - the term of the transition period; - production units; - cultures (groups of cultures), species and groups of animals.	- branches of organic production; - production units; - cultures (groups of cultures), species and groups of animals.

Figure 6. System of objects of accounting of expenses of organic production
Source: [7]

In the process of organic production, it is allowed to use only legally defined substances (ingredients, components) and in the maximum allowable quantities. The use of agrochemicals, pesticides, antibiotics for preventive purposes, hormonal drugs, animal growth stimulants, etc. is prohibited (Figures 6 and 7).

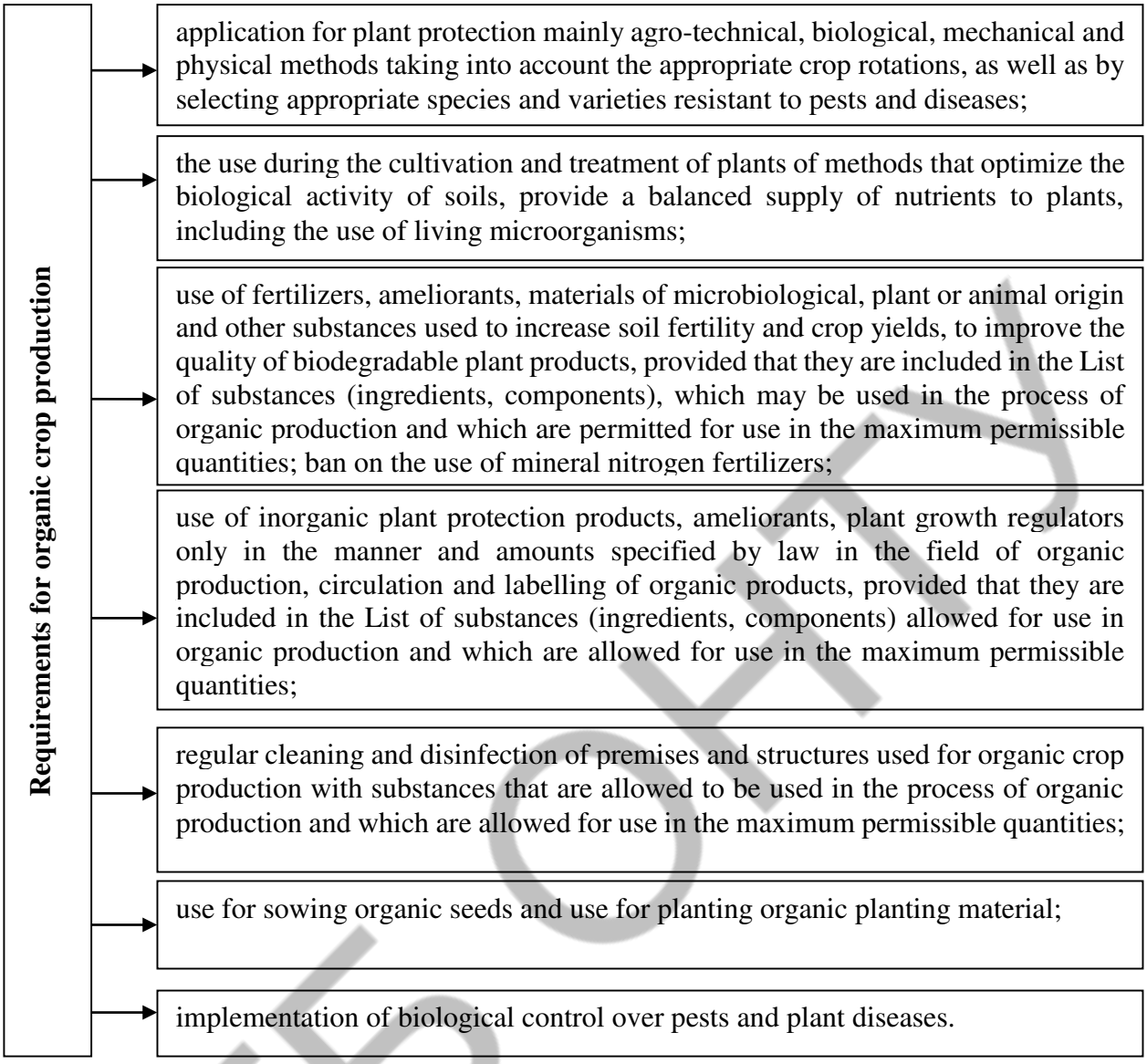

Figure 6: Requirements for the production of organic crop products
Source: [18]

These requirements and prohibitions necessitate the creation of specialized forms of primary accounting for the costs of seeds, planting material, plant and animal protection products, fertilizers to ensure effective control over the production process of organic products. It should take into account the organizational and technological features and specifics of control during the transition period, in terms of "pure" organic production and in terms of parallel production of organic and inorganic products.

During the transition period and in the conditions of parallel production of organic and inorganic products, enterprises need to organize separate storage of stocks for each of the types of production. Incoming accompanying documents should be marked, for example, "organic composition" and "inorganic composition".

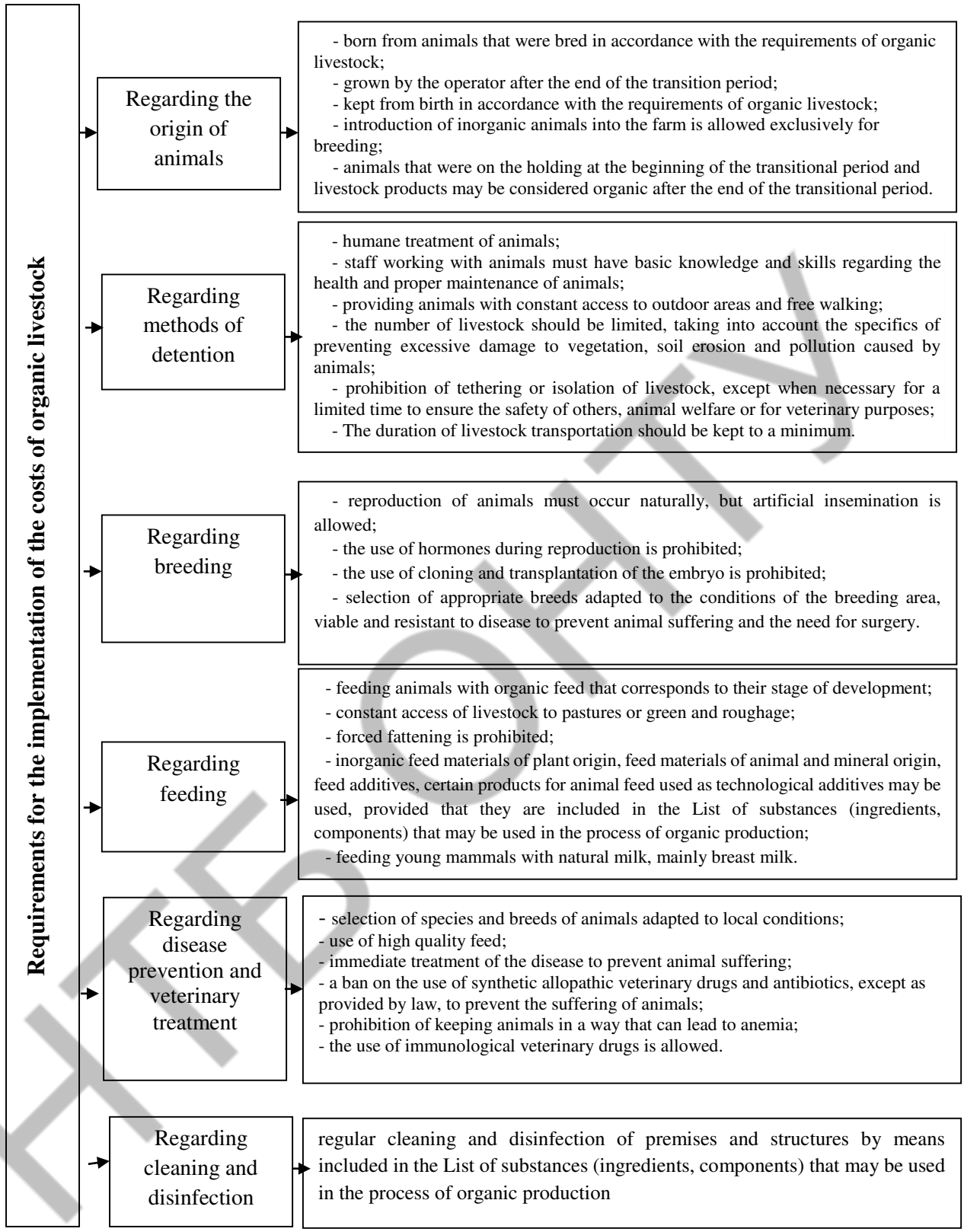

Figure 7: Requirements for the production of organic livestock products
Source: [18]

In the case of parallel production, the operator is obliged to provide the certification body with documentary evidence of compliance with the provisions of Article 26 of Law No. 2496-VIII and ensure:

– taking appropriate measures for the permanent separation of organic and inorganic products, the separation of organic and inorganic animals;

– separation of manure and feed;

– proper cleaning of production equipment for technological operations with organic products;

– submission to the certification body of information on the quantity of produced organic products and products of the transition period, inorganic products;

– submission to the certification body of information on harvesting not later than two working days before the beginning of harvesting;

– submission to the certification body of information on any movement or sale of animals, livestock products;

– submission of information to the certification body on the harvest, livestock and livestock products and measures taken to separate organic and inorganic products [17].

To provide documentary evidence of these measures to the standard and specialized agricultural forms of primary documents, it is necessary to enter additional details. It is advisable to form additional forms of documents that are necessary to confirm compliance with the law but are not in the list of already developed forms.

Legislative restrictions on organic production stipulate a particularly detailed organization of accounting for the costs of seeds, planting material, plant and animal protection products, fertilizers to ensure effective control over the production process. This can be achieved by grouping and accounting for costs by costing items.

Accordingly, enterprises operating organic production need to form an expanded nomenclature of expenditure items related to the use of these material values. We suggest that operators of organic production keep records of expenses according to the following articles:

- Salary expenses.
- Seeds and planting material:

purchased organic;

grown in the transition period;

grown in organic production;

others.

- Fuel and lubricants.
- Fertilizers:

fertilizers, ameliorants, microbiological, plant or animal origin;

other substances used to increase soil fertility and yield of biodegradable crops;

fertilizers and substances for soil improvement that can be used in the process of organic production in the maximum allowable quantities;

others.

- Plant and animal protection products:

organic plant and animal protection products;

inorganic plant and animal protection products, growth regulators are included in the List of substances (ingredients, components) that can be used in the process of organic production;

others.

- Feed:

made from organic feed materials using mainly biological, mechanical and physical production methods;

the content in the feed of not more than one ingredient of agricultural origin produced during the transition period;

purchased (meeting the requirements of organic production);

others.

- Raw materials:

raw materials and materials that can be used in the process of organic production;

raw materials and materials that can be used in the process of organic production in the maximum allowable quantities;

others.

- Works and services.
- Repair costs of non-current assets.
- Other expenses for the maintenance of fixed assets.
- Other expenses.
- Non-productive costs (accounting).
- Total production expenditures [7]

The proposed system of itemized accounting will make it possible to differentiate the costs allowed by law to be carried out in organic agricultural production and the costs of which there are certain restrictions.

V. CONCLUSIONS

The application of the proposed system of cost accounting facilities in the accounting practice of organic producers, taking into account the specifics of technological processes of organic production operators, will allow to organize separate accounting of costs for organic production, inorganic products and transition products. The introduction of the developed nomenclature of cost accounting items will make it possible to differentiate in accounting the costs allowed by law in terms of organic production from the costs of which there are certain restrictions. This will improve the information support of product quality control and will allow to adapt the accounting support of cost management of organic products to the requirements of the formation of integrated information of environmental and economic accounting.

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METHODOLOGICAL BASIS FOR ASSESSING THE INTEGRATED SECURITY OF THE ENTERPRISE

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Abstract. *The paper considers the main types and methods of assessing the level of integrated security of the enterprise. The main purpose of the study is to develop methodological foundations for assessing the level of integrated security of the motor transport enterprise (MTE). The methodical basis for assessing the level of integrated security of the enterprise, which, unlike the existing ones, is based on the assessment of the safety of the basic subsystems of the enterprise (in accordance with the resource and functional components) using the generalized desirability function and integral assessment. The scale of interpretation of the integral level of integrated security of the enterprise is developed. This methodology takes into account the influence of a complex of internal and external factors, and allows to determine the overall level of integrated security of the enterprise, problem areas of production and economic activity of enterprises that require management decisions. The results of the study can be used by domestic enterprises in the process of ensuring the required level of their security.*

Keywords: *security, integrated security, environmental safety, economic safety, evaluation, desirability function.*

I. INTRODUCTION

Intensive change of environmental factors, which causes instability of economic conditions of market participants, creates threats to their security. This situation forces enterprises to adapt to the operating conditions more quickly, requires the ability to find and implement ways to ensure stable development based on the identification, neutralization and prevention of threats. In Ukraine, full-scale hostilities led to heavy losses due to the destruction and damage of transport infrastructure, industrial and transport enterprises, etc. This has put a large number of motor transport enterprises (MTE) in Ukraine on the verge of survival. The current state of the Ukrainian economy necessitates radical changes in the security of domestic enterprises. The essence of these transformations is the implementation of a set of measures that will ensure the management of integrated security of the enterprise adequate to the conditions of its functioning in a modern competitive environment.

Despite the large number of scientific studies in the field of management and assessment of integrated security of the enterprise (ISE), approaches to defining the essence, principles, identifying factors of influence and assessing the level of integrated security of the enterprise are scattered. Therefore, there is a need to study the theoretical and methodological foundations of determining the level of integrated security of the enterprise, management of integrated security of the enterprise and substantiation of ways of their implementation, the application of which will ensure the stable development of enterprises. In this regard, the question arises about the proper

assessment of the state of security of road transport enterprises and the development of appropriate methods for its effective management. Therefore, the issue of assessing the level of integrated safety of motor transport enterprises (MTE) under the condition of environmental protection is quite relevant.

II. LITERATURE ANALYSIS

At the present stage of development of the concept of integrated security of the enterprise, considerable attention is paid to the methods of its assessment at the enterprise level, although a single comprehensive methodological approach to assessment and analysis has not yet been developed. An important element of the security management system of an economic entity is the study of modern methods and tools for assessing its level, as well as their further improvement.

Regarding the methods of safety assessment, each of the researchers formed their own vision of the need for their application in the study. At the same time, approaches to the assessment of individual components of ISE (financial and economic, physical, environmental, informational, political and legal, etc.) Let us consider the most common approaches to assessing these components of ISE.

The main approaches to quantitative assessment of the level of financial and economic security of the enterprise are summarized in Table 1.

Table 1 - The main approaches to quantitative assessment of the level of financial and economic security of the enterprise

Approach	Authors	Characteristics of the approach
1	2	3
Resource and functional	S. Pokropyvnyi, D. Kovalov, I. Pletnikova, S. Illiashenko, O. Karpenko	Provides for the definition of financial and economic security by assessing the effectiveness of the use of financial and other resources
Indicator	H. Kozachenko, V. Shlemko, M. Bermant, I. Russman, B. Koretskyi, Pochechun O.I.	It consists in establishing the level of financial and economic security as a result of comparing the actual performance of the enterprise with indicators that are the threshold values of these indicators and correspond to a certain level of security
Integral	Rzaieva T.H., Bondar H.A., Reta M.V., Ivanova A.O., Portnova H.O., Antonenko V.M.	It is based on the determination of a certain number of indicators characterizing financial stability, solvency, liquidity, return on assets, business activity, market value and investment attractiveness of the enterprise, etc. The integral value is proposed to be measured relative to normal and critical values
Point estimation	F. Yevdokimov, O. Mizina, O. Borodina	The determination of the safety level is based on the limit values of indicators and their rating. If the value of the indicator is higher than the normative, it is assigned the first class; below the normative, but above the critical - the second; below the critical - the third. The rating of the indicator is determined depending on the purpose of the study and the importance of the indicator for the chosen direction of the study

1	2	3
Program-targeted	A. Tkachenko, O. Reznikov	Based on the integration of indicators that determine the level of financial and economic security based on the methods of expert assessments
Approach based on the theory of economic risks	Klopov I. O.	Identification of various threats to the enterprise and calculation of damage, which is compared with the amount of profit, income and property
Accounting	I. V. Piriatinska	Provides for the use of criteria calculated on the basis of information from accounting and management accounting, is the possibility of using actual information about the economic activities of the enterprise in the calculations
Economic and mathematical modeling	I. V. Piriatinska, S. Kapitula, O.V. Fedosova, O.O. Molodid, S.A. Terenchuk	Based on the functional dependence of the financial level of economic security of the enterprise on the relevant performance indicators of the enterprise

Compiled on the basis of sources [1-20]

Among the above methods and techniques for assessing the integrated security of the enterprise, the authors do not have a single opinion and a single methodological approach that takes into account all security subsystems at the enterprise. Since there are different models for interpreting the essence of integrated security of the enterprise, there is also no unified approach to determining the indicators of security assessment. Therefore, it is necessary to develop a methodological approach to assess the security of each subsystem of the enterprise. Assessment of the enterprise security level involves the analysis of various aspects of its activities, according to the previously identified subsystems.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The object of research is the integrated security of the enterprise. The subject of research is the system and methods of assessing the integrated security of the enterprise.

Scientific methods used in the research: theoretical generalization and logical analysis in the analysis of modern approaches to assessing the level of integrated security of the enterprise; systematic approach in the formation of the integrated security system of the enterprise and the allocation of its main subsystems. The selection of indicator indicators was carried out using a systematic approach and logical analysis of existing methods for assessing each component of the ISE; methods of the generalized desirability function, expert survey, scoring and integral assessment, calculation and analytical in assessing the level of integrated security of the enterprise.

The purpose of the research is to deepen the theoretical foundations and develop methodological provisions for assessing the level of integrated security of the enterprise.

IV. RESULTS

The main goal of the integrated security of the enterprise is to guarantee its stable and most efficient functioning now, and high development potential in the future.

Since the integrated security of the enterprise is a system, it is a set of structural elements, each of which has its own content, set of criteria and means of ensuring. The development and implementation of a set of measures to ensure the proper condition of these subsystems is the main goal of achieving a high level of integrated security of the enterprise. But there is no single approach to the allocation of the main components of this category. Most authors [1-20] when considering the security of the enterprise define it as economic security and then distinguish other types of security in its composition.

Since the integrated security of the enterprise in the study is understood as the state of security of the activity of the economic entity and all types of resources that provide it, it is advisable to use the resource-functional approach to allocate the constituent elements of the integrated security system of the enterprise. Within the framework of this approach, a thorough study of enterprise resources is carried out. The greatest recognition of the importance of resources in the formation of mechanisms for sustainable development of the enterprise was received by the modern resource-based view (RBV), which considers the transfer of resources and abilities of the enterprise as a critical factor in generating competitive advantages [21]. Taking into account the specifics of the motor transport enterprise, the authors [22] divided resources into three main categories: material, intangible, human. Thus, when forming subsystems of integrated security, it is necessary to focus on the main groups of resources.

Taking into account the resource approach and a set of functional components, the integrated security of the enterprise is proposed to be considered as a set of security subsystems (Figure 1).

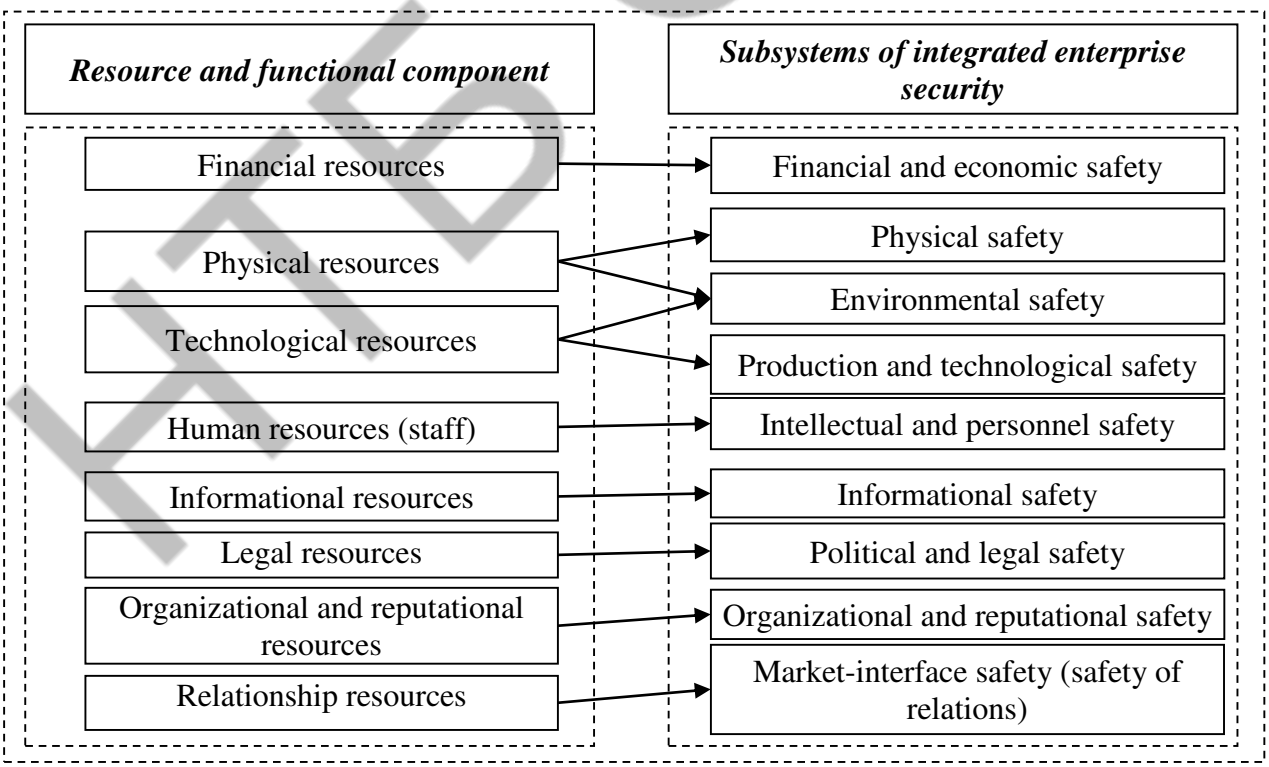

Figure 1 – The essence of the formation of an integrated security system of the motor transport enterprise

For analytical assessment of each of them, it is necessary to determine the range of possible threats (risks) and assess the probability and consequences of their implementation.

To assess the integrated safety of the enterprise, the correctness of the methodology for its implementation is important. The methodology is understood as a set of methods, rules and the most appropriate way to perform a certain work.

The purpose of the proposed methodology for assessing the ISE is to calculate and forecast its level, identify and evaluate the factors influencing the level of each component of the integrated security of enterprises, determine strategies for ensuring ISE, taking into account the impact of external and internal factors. In the proposed methodology for assessing the IS of a motor transport enterprise (Figure 2) at the first stage it is necessary to determine the object, subjects, tasks of assessment, components of the ISE, criteria and development of indicators and indicators of assessment.

It is proposed to consider the level of integrated security of the enterprise as the object of assessment, and the heads of the enterprise (their deputies) as the subjects of assessment.

It is advisable to evaluate the ISE on a quarterly basis in order to constantly monitor its activities, increase competitiveness in the market of road transport services or improve the efficiency of the road transport enterprise, etc.

Ensuring the integrated security of an enterprise necessitates the solution of a number of issues, among which the definition of criteria, indicators and indicators for assessing the integrated security of an enterprise is of particular importance. Justification of the criterion for choosing an assessment methodology for enterprises solves the question of how to compare different options for management decisions in order to make the most optimal one.

ISE indicators – are indicators for assessing the level of ISE, which allow to identify pain points in the activities of the MTE, to determine the main directions and the most effective ways to improve the efficiency of the enterprise. Indicators of the ISE level include those that quantitatively reflect the level of threat, have a significant level of sensitivity and, accordingly, the ability to warn of the possibility of danger. In addition, it is advisable to use not a separate indicator, but a system of indicators, with the help of which it becomes possible to determine the level of provision of individual internal components and/or functional components of the ISE, and further - to calculate its integral (generalized) indicator.

The generalized assessment of the level of ISE can be carried out on the basis of comparing the boundary (critical and normal) and actual values of indicator indicators. At the same time, the express assessment of the level of ISE can be carried out on the basis of graphical analysis, which allows to distinguish the zone of normal, critical safety level and pre-crisis zone.

For example, the most common indicators identified by the authors to determine the level of financial security of business entities are presented in Table 2. According to Table 2, we can say that the most common indicators for assessing the financial security of the enterprise are: autonomy ratio, coverage ratio, liquidity ratio and profitability of sales (operating profit margin).

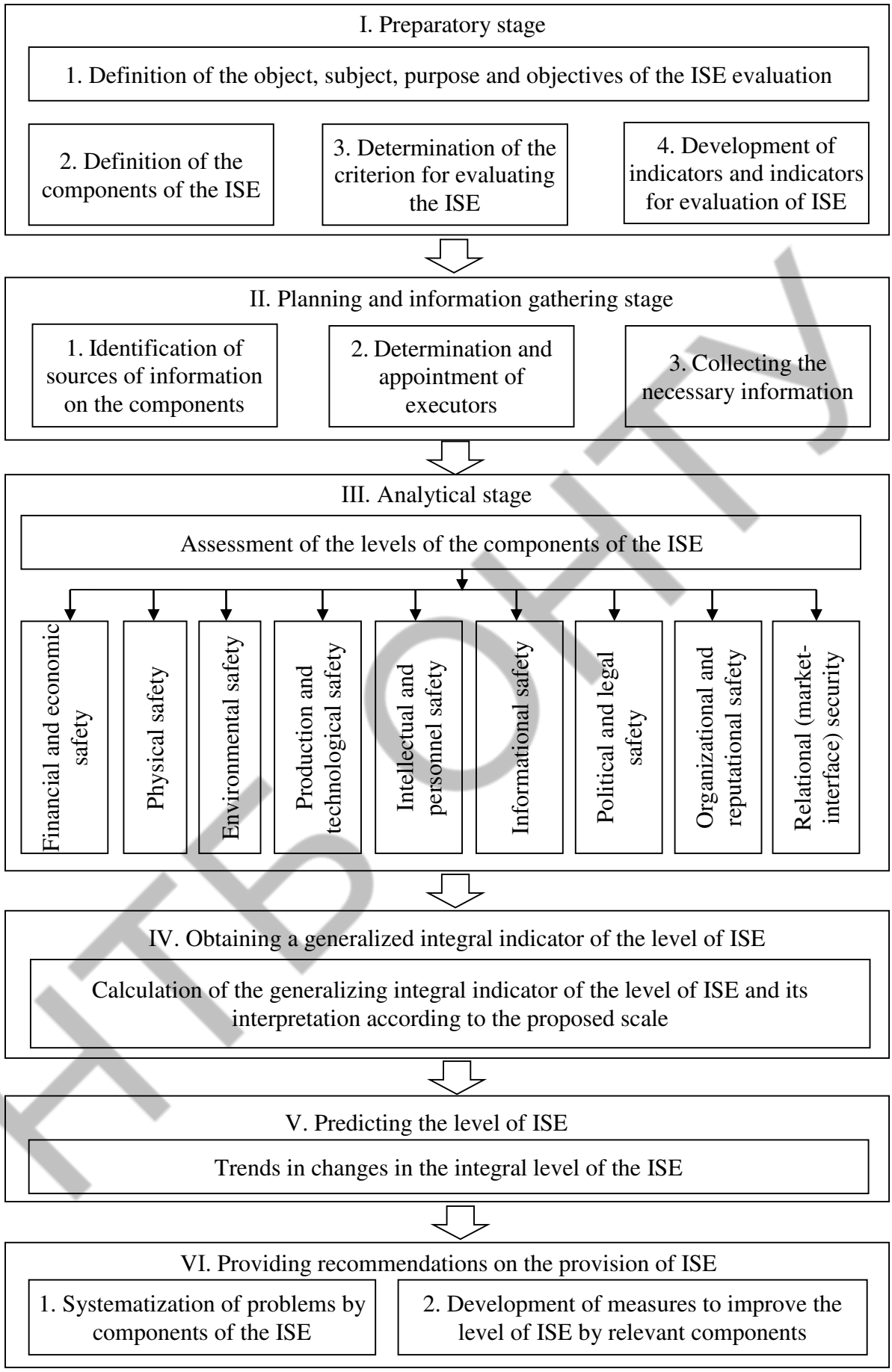

Figure 2 - Development of a methodological approach to the evaluation ISE of the MTE

Table 2 - Rationale for the choice of indicators for assessing the financial and economic component of the ISE

Indicators	Researchers							Total
	Vyshnivska B.	Horiacheva K.S.	Papekhyn R. S.	Mykhailenko V.M. , Arefiev V.O.	Arefieva O.V., Kuzenko T.B.	Oleksiv I., Podolchak N.	Kaplan R., Norton D.	
Level of accounts payable and receivable			+	+				2
Financial leverage ratio			+					1
The amount of equity and working capital		+						1
Break-even point	+							1
Profitability			+					1
Coefficient of autonomy			+		+	+		3
Coverage ratio			+		+	+		3
Maneuverability coefficient					+	+		2
Volume of loans and borrowings		+	+					2
Volume of investments		+						1
Liquidity indicator						+	+	2
Indicator of financial independence							+	1
Financial risk indicator							+	1
Turnover of current assets							+	1
Turnover of non-current assets							+	1
Profitability of assets			+				+	2
Profitability of products					+		+	2
Profitability of sales		+				+	+	3
Financial dependence ratio				+				1
Mobility coefficient				+				1
Equity maneuverability ratio				+				1
Long-term investment structure ratio				+				1
Coefficient of autonomy of sources of stock formation				+				1
Total	1	4	7	6	4	5	8	

Compiled on the basis of sources [1-20]

The creation and implementation of the indicators of the ISE has a preventive function in preventing the transition of the enterprise to a threatening state of the IS. These indicators allow timely detection of signs of significant deviations from the normal state of the IS (scale of IS).

Similarly, the indicators of each component of the ISE are selected. Based on the study of existing approaches and methods for assessing security, it is proposed to use two groups of indicators: an integral indicator - to assess the level of integrated security of the enterprise; partial indicators - for in-depth analysis of various security subsystems and identification of reserves. It is proposed to evaluate the level of ISE using nine groups of indicators for each component of the integrated security of the MTE (Table 3).

Table 3 - Indicators of ISE evaluation

Component of the ISE	Indicators
1. Financial and economic safety	1) Coefficient of autonomy; 2) Coverage ratio; 3) Liquidity ratio; 4) Profitability of sales (operating profit margin)
2. Physical safety	1) Coefficient of protection of the enterprise from illegal penetration; 2) Coefficient of physical protection of employees; 3) Coefficient of moral protection of employees
3. Environmental safety	1) Indicator of the level of compliance with emission (discharge, waste) requirements; 2) Indicator of the level of compliance with sanitary and hygienic working conditions; 3) Share of funds recovered for compensation of damage caused by violation of environmental legislation
4. Production and technological safety	1) Share of the company's products that meet the current requirements; 2) Share of RS and technological equipment that meets world analogues (current requirements); 3) Share of products of enterprises that are protected by patents; 4) Material intensity of products; 5) Capital equipment of labor; 6) Depreciation rate of fixed assets (disincentive)
5. Intellectual and personnel safety	1) Turnover rate of highly qualified workers (disincentive); 2) Share of engineering, technical and scientific workers; 3) Indicator of inventive (rationalization) activity; 4) Indicator of educational level; 5) Share of downtime in the working time fund (destimulator)
6. Information security	1) Coefficient of completeness, accuracy and timeliness of information; 2) Indicator of software and hardware security of information; 3) Share of costs for information security; 4) The level of information reliability of the staff; 5) Information security system reliability indicator
7. Political and legal security	1) Share of losses of the enterprise due to violation of legal norms; 2) The state of business documentation
8. Organizational and reputational security	1) The level of consumer perception of the company's image; 2) The level of business reputation
9. Relational (market-interface) security	1) The level of safety by external factors; 2) The level of safety by internal factors

Compiled on the basis of sources [1-20]

The generalized assessment of the level of ISE can be carried out on the basis of comparison of the boundary (critical and normal) and actual values of indicators. At the same time, an express assessment of the level of BSC can be carried out on the basis of graphical analysis, which allows to distinguish the zone of normal, critical safety level and pre-crisis zone. The normalized values calculated on the basis of the normative (limit) values of the initial indicators can be used as indicators of the ISE. Critical values of the initial indicators are determined from the condition of the minimum permissible safety level, overcoming which would mean the transition to the hazardous zone. In this case, indicators corresponding to the maximum value of the best indicators are called stimulants, and indicators corresponding to the minimum - destimulants.

For example, the assessment of the level of security by the group of indicators of financial and economic security is made by the formula:

$$d_{fes.i} = \begin{cases} 1, & if \ \ X_i^a \geq X_i^n, \\ \frac{X_i^a}{X_i^n}, & \text{if} \ \ X_i^a < X_i^n, \end{cases} \quad (1)$$

where X_i^a, X_i^n – respectively, the actual and normative (limit, maximum of the studied group) values of the indicator.

Indicators and methods of their calculation are proposed for each group of indicators for the assessment of ISE, as well as stimulators and destimulators are defined.

After calculating the value of all indicators, they are reduced to a single integral indicator by the formula:

$$\Pi i = \sum_{i=1}^{n}(1 - \delta i) \cdot Bi, \quad (2)$$

where n — number of indicators;

B_i — specific weight i-th indicator;

δ_i — relative assessment of the i-th indicator, which is calculated as (X_i/X_{max}), if a higher value of the indicator is more desirable (stimulants), or (X_{max}/X_i), if a lower value of the indicator is preferable (destimulants);

X_i — value of the i-th indicator;

X_{max} — the highest value of the indicator or coefficient for the entire analyzed period (or among comparable enterprises);

X_{min} — the lowest value of the indicator or coefficient for the entire analyzed period (or among comparable enterprises).

The second stage of assessing the level of integrated security of the enterprise is planning and collecting information, identifying performers and directly processing information about the results of the enterprise for several years. In order to assess the level of ISE, it is necessary to analyze the activity of the enterprise during a certain period, to consider the obtained indicators in dynamics, which will allow to make more complete and accurate conclusions.

The third stage is to assess the levels of each component of the integrated security of the enterprise based on the generalized desirability function. Based on statistical averages and expert opinions, the so-called "threshold" values of each component are used for the assessment indicators, which makes it possible to determine the overall level of the enterprise's IS.

The fourth stage is the assessment of the integrated security of the enterprise based on the integrated assessment to identify the overall level of integrated security of the enterprise. The closer the ratio is to one, the lower the level of ISE. It is proposed to identify certain levels of ISE for the qualitative interpretation of quantitative indicators using the Harrington's interpretation scale [23] (Table 4). This scale allows formalizing the procedure for identifying the probability and interpreting the results obtained as a result of applying the developed model for assessing the ISE.

The fifth stage is forecasting the level of the enterprise's IS and identifying trends of its change in the direction of increase, preservation or decrease.

The sixth stage is the provision of recommendations to ensure an adequate level of integrated security of the road transport enterprise: systematization of the problems of the enterprise, determination of strategies for further development of the enterprise, providing proposals for the application of organizational and economic measures to ensure the integrated security of the enterprise, taking into account the impact of external and internal factors in an unstable market environment.

Table 4 - Key to interpretation of the integral level of the ISE

Value of integral level ISE	Characteristics of the ISE level
0,00 – 0,25	The highest possible level of integrated security of the enterprise, corresponding to the state of equilibrium.
0,26 – 0,50	The average level of integrated security of the enterprise. The enterprise is functioning normally, but there are certain problems related to the inefficient organization of the main activity, which generate the possibility of a threat to integrated security in the future.
0,51 – 0,75	Low level of integrated security of the enterprise. Negative trends in indicators characterizing the financial and economic spectrum of the enterprise are increasing. There are processes that indicate an increase in threats in the relevant areas of integrated security of the enterprise.
0,76 – 1,00	Crisis state of safety at the enterprise. There are chronic violations of functioning parameters by all assessment criteria.

By forming an integrated security management mechanism, enterprises will be able to meet the requirements of sustainable development and viability.

Testing of the proposed methodological approach to assessing the level of IPA was carried out on the private joint-stock company data «Kharkiv MTE-16355». Here are more detailed calculations for one subsystem of the IPPC - the subsystem of environmental safety. First, let's calculate the level of compliance with emissions (discharges, waste) requirements. To assess the environmental safety of the MTE by the main types of negative impact on the environment (emissions, discharges, waste), the generalized desirability function [23] is calculated by the formula of the geometric mean weighted set of real numbers ($d_1 ... d_n$) with weight ($\alpha_1 ... \alpha_n$; $\beta_1 ... \beta_n$) and is defined as:

$$D = \sqrt[k]{\prod_{i=1}^{n}(d_i^{\alpha})^{\beta}} = \sqrt[k]{d_1^{\alpha\beta} \cdot d_2^{\alpha\beta} \cdot d_3^{\alpha\beta} \dots \cdot d_n^{\alpha\beta}}, \quad (3)$$

where n - number of indicators;

d_i - private desirability function;

α і β – weighting coefficients.

$$K = \sum_{i=1}^{n} \alpha_i \cdot \beta_i. \quad (4)$$

The following interpretation of the weighting coefficients is proposed:

α_i - is the coefficient that takes into account the hazard class of the i-th pollutant;

β_i - coefficient that takes into account the excess of the average measured value of the indicator concentration over the standard. The generalized desirability function is the geometric mean of the private desirability functions (d_i), and if at least one of d_i is zero, then D = 0. There is some excess of waste to surface water and solid waste production.

Next, let us consider in more detail the calculation of the compliance assessment of waste emissions from auxiliary processes of the MTE (Table 5).

Table 5 - Input data for estimating the level of waste from technical service and repair rolling stock

Name of the indicator	X_i	$X_{standard}$	d_i	α	β	α*β
Annual level of waste to surface water bodies per one accounting vehicle, kg						
dry residue	80	76	0,999	1	1,053	1,053
chlorides	16	17	0,998	0,25	0,941	0,235
sulphates	6	4	0,923	1	1,500	1,500
suspensions	1,2	1	0,984	1	1,200	1,200
other	1,8	2	0,994	0,25	0,900	0,225
Annual volume of solid waste removed from the MTE per one accounting vehicle, kg						
dust	110	102,5	0,998	1	1,073	1,073
consumption waste	50	47,5	0,999	1	1,053	1,053
wood waste	28	35	0,976	0,25	0,800	0,200
waste paper	34	35	1,000	0,25	0,971	0,243
brake pads	10,5	10	0,999	1	1,050	1,050
glassblower	16	15	0,998	1	1,067	1,067
rubber (except tires)	4,8	5	0,999	0,25	0,960	0,240
Annual volume of waste transferred by MTE for further processing to other organizations per one accounting vehicle, kg						
ferrous metal scrap	310	342	0,995	0,25	0,906	0,227
sludge from sewage treatment plants	240	279	0,989	0,25	0,860	0,215
car tyres	160	180	0,993	0,25	0,889	0,222
used oils and lubricants	78	81	0,999	0,25	0,963	0,241
scrap of batteries	16	18	0,993	0,25	0,889	0,222

There is some excess of waste to surface water and solid waste production. Table 6 calculates the indicators of waste level assessment from maintenance and repair of rolling stock of MTE.

Table 6 - Assessment of the level of waste from technical service and repair of rolling stock

Name of the indicator	α*β	K	$d_i^{\alpha\beta}$	Assessment level waste
Annual level of waste to surface water bodies per one accounting vehicle, kg				
dry residue	1,053	4,213	0,999	0,967
chlorides	0,235		1,000	
sulphates	1,500		0,887	
suspensions	1,200		0,980	
other	0,225		0,999	
Annual volume of solid waste removed from the MTE per one accounting vehicle, kg				
dust	1,073	4,925	0,997	0,997
consumption waste	1,053		0,999	
wood waste	0,200		0,995	
waste paper	0,243		1,000	
brake pads	1,050		0,999	
glassblower	1,067		0,998	
rubber (except tires)	0,240		1,000	

Annual volume of waste transferred by ATP for further processing to other organizations per one accounting vehicle, kg				
ferrous metal scrap	0,227	1,127	0,999	0,994
sludge from sewage treatment plants	0,215		0,998	
car tyres	0,222		0,998	
used oils and lubricants	0,241		1,000	
scrap of batteries	0,222		0,998	
Total waste		10,265		0,984

According to Table 6, it can be seen that the assessment of the environmental component of the ISE in terms of waste from rolling stock maintenance and repair is at a fairly high level and is equal to 0.984. However, it is still necessary to take into account the level of discharges (waste) from additional services, the quality of treatment facilities, the level of emissions from vehicles, etc. This assessment is made using a rating scale developed according to the relevant Euro 1 - Euro 6 standards. In this case, for MTE all vehicles meet the environmental standards Euro 4-6. In general, the value of this indicator for MTE is the geometric mean of all vehicles. The generalized indicator of the level of compliance with the requirements of emissions (discharges, waste) is 0.56.

Table 7 shows the assessment of sanitary and hygienic working conditions of drivers according to the appropriate scale. Assessment of sanitary and hygienic working conditions of car drivers is carried out according to the developed scale.

Table 7 – Assessment of sanitary and hygienic working conditions of the driver's team

Elements of working conditions	Assessment of working conditions by drivers															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Air temperature at the workplace, °C	5	5	4	5	5	5	5	4	4	5	5	4	5	4	5	5
Toxic substances	5	4	4	4	4	5	4	4	4	4	4	5	4	4	5	5
Industrial dust	3	3	4	3	4	3	3	3	3	3	4	3	3	5	4	3
Vibration	3	4	4	4	4	5	3	5	3	3	4	4	3	4	4	5
Noise	5	4	3	5	3	4	4	5	3	3	5	3	5	4	3	4
Sum of points	21	20	19	21	20	22	19	21	17	18	22	19	20	21	21	22

$d_{work.cond}$=(21+20+19+21+20+22+19+21+17+18+22+19+20+21+21+22)/(5·6·16) =0,67.

After calculating the level of sanitary and hygienic working conditions of all groups of the company's personnel, this figure was 0,32.

Similarly, the calculation is carried out for all other security components. The results of the assessment of the level of ISE for all components (according to formula 3) for the private joint-stock company «Kharkiv MTE-16355» are shown in Table 8.

According to the study, it was found that MTE-16355 currently has an average level of Coefficient of Performance (0,413), that is, the enterprise is functioning normally, but there are certain problems associated with the inefficient organization of

the main activity, which generate the possibility of a threat to comprehensive security in the future.

Table 8 - Assessment of the level of integrated security of MTE

Component of the ISE	Evaluation indicators	Normalized value of the indicator	Weight of the indicator	Balanced assessment
1	2	3	4	5
Financial and economic safety	Coefficient of autonomy	0,40	0,032	0,013
	Coverage ratio	0,38	0,040	0,015
	Liquidity ratio	0,39	0,045	0,017
	Profitability of sales (operating profit margin)	0,41	0,043	0,018
	Financial and economic component of the ISE	**-**	***0,160***	***0,063***
Physical safety	Coefficient of protection of the enterprise from illegal penetration	0,49	0,035	0,017
	Coefficient of physical protection of employees	0,52	0,028	0,015
	Coefficient of moral protection of employees	0,48	0,017	0,008
	Physical component of the ISE	**-**	***0,080***	***0,040***
Environmental safety	Indicator of the level of compliance with emission (discharge, waste) requirements	0,56	0,059	0,033
	Indicator of the level of compliance with sanitary and hygienic working conditions	0,32	0,054	0,017
	Share of funds recovered for compensation of damage caused by violation of environmental legislation	0,44	0,038	0,017
	Environmental component of the ISE	**-**	***0,150***	***0,067***
Production and technological safety	Share of the company's products that meet the current requirements	0,22	0,022	0,005
	Share of RS and technological equipment that meets world analogues (current requirements)	0,25	0,026	0,007
	Share of products of enterprises that are protected by patents	0,30	0,018	0,005
	Share of products of enterprises that are protected by patents	0,44	0,022	0,010
	Capital equipment of labor	0,56	0,020	0,011
	Depreciation rate of fixed assets (disincentive)	0,52	0,022	0,011
	Production and technological component of ISE	**-**	***0,130***	***0,049***
Intellectual and personnel safety	Turnover rate of highly qualified workers (disincentive)	0,44	0,022	0,010
	Share of engineering, technical and scientific workers	0,61	0,017	0,010
	Indicator of inventive (rationalization) activity	0,28	0,016	0,005
	Indicator of educational level	0,63	0,022	0,014
	Share of downtime in the working time fund (destimulator)	0,56	0,014	0,008
	Intellectual and personnel component of the ISE	**-**	***0,090***	***0,046***
Informational safety	Coefficient of completeness, accuracy and timeliness of information	0,54	0,024	0,013
	Indicator of software and hardware security of information	0,32	0,022	0,007

1	2	3	4	5
Informational safety	Share of costs for information security	0,30	0,021	0,006
	The level of information reliability of the staff	0,39	0,020	0,008
	Information security system reliability indicator	0,35	0,023	0,008
	Information component of the ISE	-	***0,110***	***0,042***
Political and legal safety	Share of losses of the enterprise due to violation of legal norms	0,18	0,039	0,007
	The state of business documentation	0,45	0,041	0,018
	Political and legal component of the ISE	-	***0,080***	***0,025***
Organizational and reputational safety	The level of consumer perception of the company's image	0,52	0,061	0,031
	The level of business reputation	0,44	0,050	0,022
	Organizational and reputational component of the ISE	-	0,110	0,053
Market and interface safety	Security level by external factors	0,29	0,058	0,017
	Security level by internal factors	0,35	0,032	0,011
	Market-interface component of the ISE	-	***0,090***	***0,028***
The overall level of integrated security of the enterprise		-	*1,000*	*0,413*

The most significant negative impact on the ISE is observed in the environmental (0,067), financial and economic (0,063) and organizational and reputational (0,053) components of the ISE. Thus, it is necessary to consider and propose strategies for the development of integrated security of the enterprise by various components and introduce measures to improve it.

V. CONCLUSIONS

The methodological basis for assessing the integrated security of the enterprise for each of its components, based on the methods of the generalized desirability function and integral assessment, has been improved, and a scale for interpreting the integrated level of integrated security of the enterprise has been developed.

Thus, according to the results of the study, the methodological foundations for assessing the level of integrated security of the enterprise were improved, which, unlike the existing ones, is based on the methods of the generalized desirability function and integral assessment, and a scale for interpreting the integrated level of integrated security of the enterprise was developed. This methodology takes into account the influence of a complex of internal and external factors, and allows to determine the overall level of integrated security of the enterprise, problem areas of production and economic activity of enterprises that require management decisions. The results of the study can be used by domestic motor transport enterprises in the process of ensuring the required level of their safety.

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CONTEMPORARY ASPECTS OF THE ANALYSIS OF CURRENT ASSETS IN THE ENTERPRISE MANAGEMENT SYSTEM

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Abstract: *The purpose of the study is to analyze scientific works devoted to the conceptual and categorical apparatus of the category "current assets" in modern conditions and their classification, to study approaches to the financial analysis of current assets and the efficiency of the use of the company's working capital in a theoretical and practical aspect, substantiation of the need to form a comprehensive approach before carrying out such a financial analysis in the enterprise management system.*

The scientific result of the study is the formation of a comprehensive approach to the financial analysis of the current assets of the enterprise and its important elements, which is relevant in the modern market conditions of the operation of the enterprise and includes the analysis of its dynamics, structure, turnover, financial cycle of operating activities, the impact of changes in current assets and their turnover on liquidity of assets and financial condition of the enterprise. The practical significance of this work is aimed at the use of this approach to the financial analysis of current assets and the use of working capital as a tool in the management system of the operational activities of enterprises to ensure the efficiency of their functioning and management. The possibility of economic transformation of the operational activities of agro-industrial complex enterprises in modern conditions to ensure the preservation of domestic producers and their activities in Ukraine has been considered.

Keywords: *current assets, working capital, enterprise, management system, financial analysis, economic transformation.*

I. INTRODUCTION

The activity of any enterprise begins with the formation of assets, which are formed at the expense of own and borrowed capital. An indispensable condition for an enterprise to carry out effective economic activity is the availability of current assets, which, together with the labor force, are the most important element of production. Insufficient provision of the enterprise with current assets paralyzes its activity and leads to deterioration of the financial situation.

The study of statistical data for 2016-2019 showed [1, p. 416-419] that in Ukraine the working capital of enterprises invested in its current assets makes up 56-57% of the total structure of invested capital: in 2016 – 57.8%, in 2017 – 56.7%, in 2018 – 57.8%, in 2019 57.7%, and in industry it varies from 51.5% to 56.7%: in 2016 – 54.4%, in 2017-2018 – 56.7% and 55.8%, respectively, and in 2019 – already 51.5%. As a source of financing the working capital of enterprises, equity in the total amount of capital had a share of more than 24% in 2016-2018, but in 2019 amounted to 26.9%, but its share is significantly lower in industrial enterprises - from 17% to almost 19% in 2016-2018, with its growth in 2019 to 24.3%. Indicators of the state and changes in

the working capital of enterprises, which is invested in its current assets, in 2020-2021 have a tendency to deteriorate [2, p. 27-28, 43-44; 3, p. 398-404]. Such dynamics of equity capital, as a source of financing working capital invested in its current assets, is negative from the point of view of the financial condition of enterprises, where for a normal financial condition, equity capital should be at least 50% of the total capital of the enterprise with a significant share of current assets in their total amount. Changes in statistical data confirm the need to find working capital management tools and directions for accelerating its turnover and improving the financing of the company's operational activities in its management system. Ensuring the financing of stocks and the functioning and efficiency of the operational activities of enterprises with own working capital is a particularly important issue in the modern era of military aggression of the Russian Federation in order to preserve its own producer and ensure the functioning of the Ukrainian economy.

The first stage in the management system of any element of the enterprise's activity and the formation of an effective policy is an economic analysis. In the context of our research, such a tool for analyzing the working capital of an enterprise, which is invested in its current assets, is its financial analysis according to the established methodology. Research on the financial analysis of current assets and management of the working capital of the enterprise, which is invested in their elements, was studied by Ukrainian and foreign scientists, such as Antonyuk O., Barabash N., Baumol U., Bilyk M., Blank I., Butynts F., Brigheim Y., Burkinsky B., Bursuk G., Butenko A., Horovy D., Zolotaryov A., Kireytsev H., Konovalova O., Kramarenko G., Myers S., Martin D., Merton R., Matviyuk A., Miller M., Mets V., Mnih E., Nashkerska G.V., Nevmerzhitska N., Orr D., Osypov P., Pavlenko O., Pavlovska O., Prytulyak N., Podderegin A, Savchenko A. , Stoyanova O., Tarasenko O., Tereshchenko O., Tomkins D., Sheremet V., Frolov V., Tsal-Tsalko Y., etc., but need additional research into the theoretical aspects of definition, classification and methods of implementation, and practical aspects application at the enterprise for the purpose of effective use of current assets in the system of its management of its operational activities.

II. LITERATURE ANALYSIS

The study of current assets in the enterprise management system is not possible without determining their essence, classification and methods of conducting financial analysis in accordance with the tasks and directions.

2.1. Determination of the nature and classification of current assets enterprises

According to the National Regulation (standard) of accounting 1 "General requirements for financial reporting", current assets are "money and its equivalents, which are not limited in use, as well as other assets intended for sale or consumption during the operating cycle or within twelve months from balance sheet dates" [4]. In this definition, essential characteristics such as "cash and cash equivalents, which are not restricted in use", "intended for sale or consumption during the operating cycle" are quite appropriately used. The first characteristic testifies to the unlimited use of funds belonging to the company's current assets, and the next - to the time frame of the use

of current assets. These characteristics are interrelated, because the unlimited use of them is explained by the fact that, in any case, a certain amount of assets must be used during one operational cycle [5].

In turn, according to International Accounting Standard 1 "Presentation of Financial Statements" (hereinafter – IAS), current assets are interpreted as "current". Current assets are recognized as [6]:

– can be implemented or consumed in the normal operating cycle;

– are held mainly for the purpose of sale;

– can be implemented within twelve months after the reporting period;

– are cash or cash equivalents, provided that there are no restrictions on the exchange or use of this asset to settle the obligation for at least twelve months after the reporting period.

Having compared the definitions of current assets in domestic and international regulatory documents, it can be said that the domestic interpretation corresponds to the international one.

In the Economic Code of Ukraine, there is no interpretation of such a category as "current assets" at all, but in Article 139 "Property in the sphere of management" it is stated that "current assets are raw materials, fuel, materials, low-value items and items that wear out quickly, other property production and non-production purposes, which are classified by legislation as current assets" [7].

Among modern domestic and foreign economists, there is also a lack of agreement regarding these concepts. Some researchers consider the concepts of "current assets", "working capital", "current assets", "current funds", "current assets" to be synonymous [8-10], others combine only some concepts [11] , the third group of scientists note that the economic meaning of these concepts is different, which is why it is wrong to equate them [12-15].

The inaccuracy of equating current assets with working capital is that the generally accepted division of working capital into working capital and circulation funds does not take into account such a part of the enterprise's economic means as short-term financial investments. Current assets include both material and monetary resources, therefore, the concept of current assets is broader than the concept of working capital.

Our research showed [16] that among scientists there are various definitions of the essence of the concept of "current assets", some of which are listed in Addendum A of the table. A.1.

Our study of approaches to defining the essence of the category "current assets" and "circulating assets" using a scientific approach allowed us to single out several approaches (directions) to explaining the essence of the concept of "current assets" [16-17]:

– scientists T. A. Demchenko, H. G. Kireytsev consider current assets to be "a set of current funds and circulating funds or funds advanced from them" [21, 25] - this definition, in their opinion, reflects the essence of current assets as a value category, since "current assets include production stocks, work-in-progress, semi-finished products of own production and costs of future periods, and current assets include finished products, receivables and cash." But according to the IASB, the category of

working capital and circulating assets is not used in the IASB, and current assets in the modern economy and regulatory sources are a set of working capital and means of circulation or cash advanced to them, which are placed in the sphere of production and the sphere of circulation;

– on the basis of the "separate, precisely monetary nature of current assets", the definition of scientists Braley R. and Myers S., Nashkerskaya G.V., Zvi Bodi and Robert Merton is based [16-17,26];

– focusing on the term of use of current assets is the most common approach in economic literature (Blank I.O. and Slav'yuk R.A.), according to which "current assets are interpreted as a set of property values that serve the subject's current economic activity management and are completely consumed during one operational cycle" [19, 22];

– the understanding of current assets as a natural-material category, i.e. as "enterprise assets that fully transfer their value to the value of the produced products" (V.V. Kovalev and O.S. Filimonenkov [27, 28]).

We share the opinion of V.V. Kovalev. and Filmenkova O.S. [17], who believe that "under the conditions of established commodity-money relations, the material assets of enterprises are expressed not only in natural, but also in value form. Current assets include both material and monetary resources," therefore, identifying them with money is economically impractical, and the opinion of Blank I.O. and Slav'yuk R.A., who believe that "in the economic essence, current assets should be understood as resources controlled by a business entity that can be used in the production process and transfer their value to finished products or can be converted into cash within one operational cycle" [19,20].

The table A.2 Addendum A shows that the interpretation of current assets according to national standards corresponds to international ones.

Our study of definitions of the category "current assets of the enterprise" existing in regulatory documents and literary sources allows us to assert the presence of different views on its economic meaning[16]. It should be noted that the definitions of the category "current assets" have a lot in common both in terms of content and methods of influencing the object of management (current assets), and the value advanced in them is the working capital of the enterprise. In a large number of economic works, current assets are considered either as an exclusively economic category, and then their material side comes to the fore; or as a purely financial category, and then the main attention is paid to the sources of formation of current assets. But such a duality of the nature of current assets lies in their material, as well as in value or monetary characteristics, in the fact that assets are both the source and the result of the enterprise's activity, regardless of the specifics of the production activity. That is, current assets always reflect the nature of the placement of invested capital in the process of economic activity. In addition, many definitions of current assets do not specify the final purpose of their use. The study of the essence of the category "current assets" showed that they represent an economic category that combines certain theoretical and practical aspects (Addendum A, Table A.3).

There is a relatively close relationship between certain aspects of the category of current assets. The stable financial condition and development of the enterprise is based

on the adoption of progressive management decisions to improve the efficiency of the use of current assets. Thus, the term current assets at the current stage of the development of economic science must reflect all four aspects of the enterprise's activity, take into account the purpose of activity, economic conditions, peculiarities of the functioning of enterprises and the role of current assets in the reproduction process. A mandatory condition for the functioning of current assets is their continuous movement or turnover of assets [24]. Management of the company's current assets is not possible without an approach to their classification depending on the tasks of their management.

2.2. Analysis of approaches to the classification of current assets of the enterprise

Our study showed that the classification of current assets according to various characteristics allows us to evaluate the current assets of the enterprise for their successful management [16-17]. Yes, according to Prof. F.F. Butynets, "the classification of elements is based on the connection between them, which is expressed in their placement and in a certain sequence of the defined system in relation to certain general principles. In scientific practice, a certain systematization of knowledge about one or another subject is provided" [20].

Domestic economists distinguish different classification groups of current assets, relying mainly on international practice. The most common classification features are the classification of current assets depending on participation in circulation, on the nature of financial sources of formation and on types. But to date, there is no single approach to the classification of current assets in the economic literature. Most scientists use the same characteristics to classify current assets, therefore, in our opinion, it is appropriate to summarize their scientific approaches to this issue with the help of a table. B.1 of Addendum B.

The data in Table B.1 of Addendum B shows that the classification of current assets, like assets in general, is quite broad and has many features. It can be noted that a number of authors [27,29,30,33,35,36] classify specifically tangible current assets, which include labor items (intended for consumption during the normal operating cycle); finished products; goods. Other groups of scientists classify the entire set of current assets according to separate characteristics: according to the degree of liquidity, according to the level of their market (possible) value, depending on the speed of circulation [18,19,23,28, 31,32,34,38-43]. But according to scientists, the most effective classification for modern management, organization of more effective and efficient accounting, analysis, audit and management at the enterprise, risk management, liquidity, protection against inflation, speed of circulation and level of profitability is the classification of current assets proposed by E.O. Donin [16, 29].

Our analysis shows [16, 17] that there is no comprehensive classification in the economic literature, which includes the most common classification features. But a large number of different classifications are considered, in which signs are duplicated or have different names, without changing their essence. Therefore, when defining a certain type of current asset, there are difficulties in its definition, which leads to both an erroneous definition and a negative impact on the effectiveness of its management.

Less common in the economic literature, as our study [17] showed, is the distribution by degree of protection against inflation, by investment risk, by degree of liquidity, by period and form of functioning, etc. Normative classification of current assets is given in IAS 1 "Presentation of financial statements" [44], but in this standard current assets are considered according to only one classification feature - by their types. This classification is carried out using the characteristics of the items of the second asset section of the balance sheet "Current assets", and is most widely used for accounting purposes in the practical activities of enterprises. Therefore, it is important to classify current assets for the efficiency of the enterprise's functioning - according to their practical use in modern conditions (table B.2 of Addendum B).

As our study [16] showed, given the high level of inflationary processes that is characteristic of the economy of Ukraine in the recent period, it is interesting to classify current assets according to the degree of protection against inflation. A number of such authors as Sikora I., Chebanova N.V. propose to classify current assets, dividing them depending on inflation protection into [16,44]:

– assets protected from inflationary depreciation (tangible current assets, secured receivables, effective financial investments, foreign exchange funds);

– assets not protected from inflation (cash in national currency, unsecured receivables, inefficient financial investments).

The mentioned scientists singled out such a classification feature, because it is conditional, because only the assets produced at the enterprise are not directly affected by inflation, and inflation has the most direct effect on the depreciation of monetary funds.

In the conditions of anti-crisis management of assets, there is a need to distribute their elements according to the level of profitability, because for an enterprise, profit is more important than income, since it is profit that characterizes the final results of the enterprises. According to this feature, current assets are divided into the following types [16]:

– highly profitable (current financial investments, deposits);

– medium-profit (finished products, accounts receivable);

– non-profit (stocks of goods and material resources, finished products that are not in demand, cash);

– unprofitable (part of stocks of goods and material resources, the quality and quantity of which decreases during the storage process, bad debts). A large presence of unprofitable assets can threaten the enterprise with bankruptcy.

The importance of this classification criterion is determined by the fact that the accounting of assets by the level of profitability characterizes the economic efficiency of their use and makes it possible to predict the profitability of the company's assets.

Based on the results of our analysis of regulatory acts and scientific sources [16-17], the classification of current assets by types (elements) considered in international and national accounting standards was summarized (table B.3 of Addendum B). The table B.3 of Appendix B shows that current assets according to national and international standards include the same basic elements: stocks, receivables, cash (there are no other current assets according to IAS). But the differences are precisely in the composition of the elements. Yes, according to IAS, there are advance payments in

stocks, but there is no element of current biological assets. Also, according to IAS, investments and receivables by types of capital are considered in more detail, however, according to national standards, receivables are calculated.

Thus, the formation of different approaches to the classification of current assets influence their management, but it is necessary to use such classification for modern management, organization of more effective and efficient accounting, analysis, audit and management at the enterprise, risk management, liquidity, protection against inflation, speed of circulation and level of profitability.

2.3. Analysis of approaches to financial analysis of current assets of the enterprise

In order to form an effective management policy of current assets in the management system of the company's operational activities, it is necessary to use such a tool as a comprehensive financial analysis of them, which is precisely the first stage of their management policy.

Our research has shown [46-47] that in the publications of scientists and practical sources there are many approaches to distinguishing the stages of analysis of current assets, as each of them distinguishes, from its point of view, the key stages of such an analysis. Some of them are common to most research by scientists, such as the analysis of the composition, structure and dynamics of assets, current assets and their elements, sources of their financing, turnover of current assets and their elements, profitability of current assets and its factor analysis (table C. 1 of Addendum C).

According to I.O. Form [53] the analysis of current assets should begin precisely with the consideration of the dynamics of the total volume of current assets in use - the rate of change in their average amount is compared with the rate of change in the volume of sales of products (works, services) and with the average amount of all assets. But, according to Yu.S. Tsal-Tsalko [56], V.O. Metsa [55], E.V. Mnikha, N.S. Barabasha [37], G.O. Kramarenko [54], Savchenko A.M., Matviyuka A.V. [52] the analysis of current assets must begin with an assessment of the dynamics of the main types of current assets and an assessment of their liquidity. Only some scientists [46-48,50] pay attention to the analysis of the causes of changes in current assets, i.e. factor analysis of changes in current assets. The need for its implementation, in our opinion, lies in the fact that all phenomena and processes of the enterprise's economic activity are interconnected, and any result of the activity depends on various factors. Therefore, it is important to manage the assets in which the company's capital is invested is the issue of studying, measuring, and analyzing the impact of factors on the value of indicators of current assets.

Our previous study showed [47] that one of the important stages of the analysis of current assets is the analysis of the composition, structure and dynamics of its elements, such as cash, stocks and receivables, which requires the formation of stages of a comprehensive financial analysis of current assets in the management system operational activity of the enterprise.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The object of research is the current assets of the enterprise, and the subject is theoretical and practical approaches to the financial analysis of the current assets of the enterprise in the management system in modern conditions of its functioning. The theoretical and practical basis of the research is the study of domestic and foreign scientific and practical works on this problem, normative documents and national and international provisions (standards) of accounting, legislative acts, statistical data, financial reporting indicators of agro-industrial enterprises, informational materials of Internet sites.

The following methods were used to solve the research tasks: the method of structural and logical analysis – when forming the structure and logic of scientific work; methods of theoretical generalization and comparative analysis – for research and selection of the conceptual apparatus of the "current assets" category and their classification; the method of analysis, synthesis and grouping – for the analysis of approaches to the classification of the company's current assets; the method of absolute and relative values, comparative analysis, graphical method – for conducting a financial analysis of the company's current assets.

IV. RESULTS

Our research confirms [46,47,61-63] the need for a comprehensive approach to conducting a financial analysis of the company's current assets, in which its working capital is invested, as the first stage of forming a working capital management policy in the enterprise management system. This approach allows not only to develop an effective policy of managing current assets and the use of the company's working capital, but also to carry out constant monitoring of changes in absolute and relative indicators characterizing the state and use of elements of current assets in the company's management system to ensure its effective functioning, development of activities, increase of investment attractiveness and financial stability and competitiveness. The application of a complex approach to financial analysis consists in the fact that all phenomena and processes of the enterprise's economic activity are interconnected, and any result of activity depends on various factors.

Thus, the results of the study made it possible to form the stages of conducting a financial analysis of the company's current assets for the purpose of effective management and its functioning (Fig. 1).

The conducted study of theoretical aspects and scientific publications of scientists regarding the financial analysis of the current assets of enterprises and its important elements and the efficiency of the use of working capital requires the testing of such a comprehensive methodical approach proposed on the example of two production enterprises of the Odesa region's agricultural industry - "Druzhba SVK" LLC (Addendum D). and PJSC "Veselo-kutskiy combine of bread products" (Addendum E). In our opinion, such an approach to the financial analysis of current assets and the use of working capital will be essential for the development of their management policy in the enterprise management system to ensure financing with own working capital of the stock, functioning and efficiency of the enterprise's operational activities, will positively affect its liquidity and solvency in the modern time of military

aggression of the Russian Federation to preserve its own commodity production and ensure the functioning of Ukraine's economy.

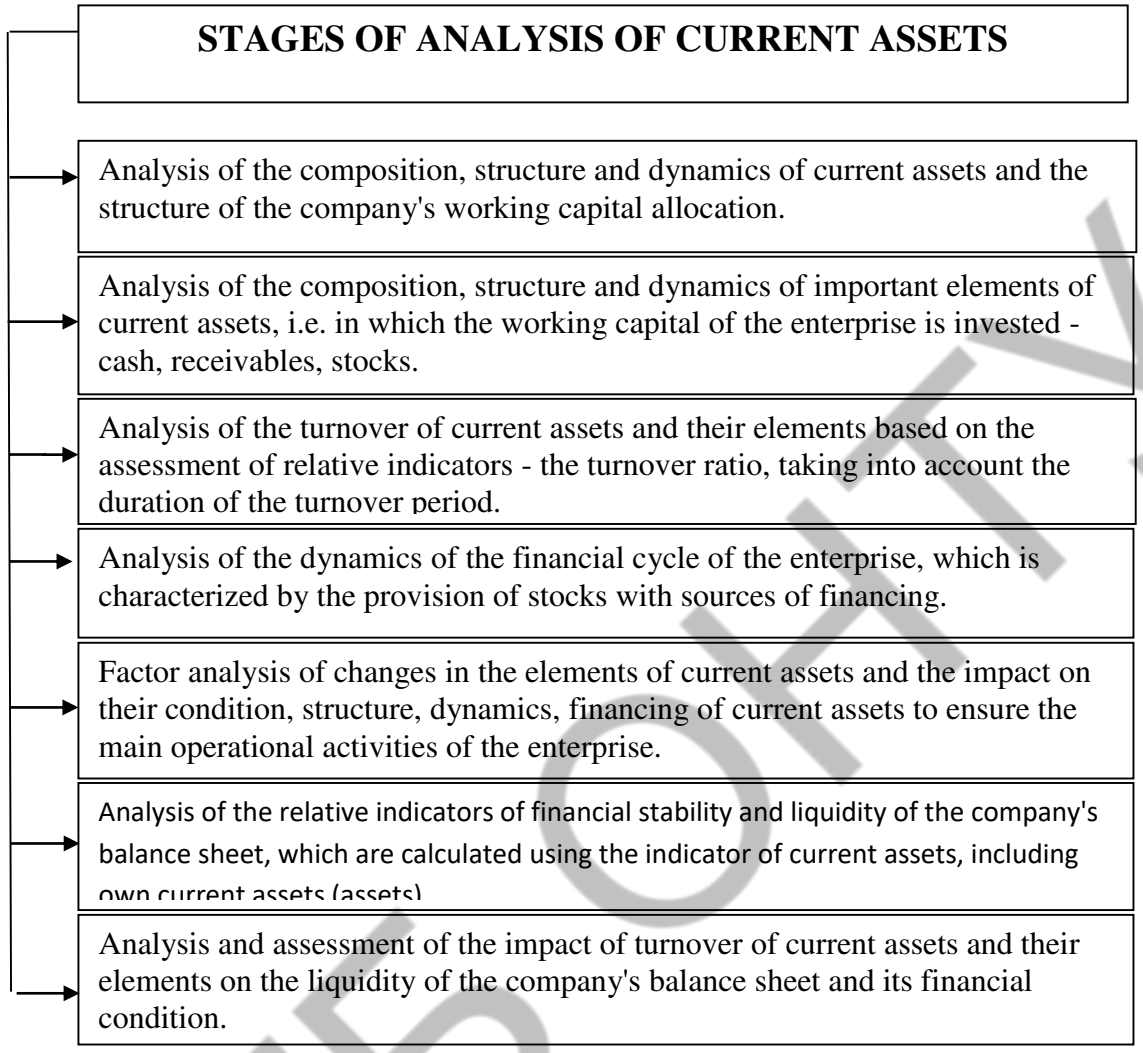

Fig. 1. Stages of analysis of current assets of the enterprise*

*Formed by the author [61] based on research of sources [43,45,48-58]

A detailed analysis of important elements of current assets, such as cash, stocks and accounts receivable, will allow constant monitoring of their condition, structure and dynamics, which will hide their effective management and prevent the diversion of working capital from the turnover of the enterprise and the process of normal financing of its activities.

Therefore, an important stage of the analysis of current assets, in our opinion, is the calculation of the dynamics of the financial cycle of the enterprise, which was studied by scientists (Table 1) and is of great importance in the practical activity of the enterprise.

Table 1. Peculiarities of calculating the financial cycle of the enterprise in scientific sources *,**

Indicator	Author, source				
	Yehorova O.V., Darohan-Pysarenko L.O., Tyutyunnyk.M., [49]	Prib K.A., N.I. Patyka, [51]	Blank I.A., [58]	Mets V.O., [55]	Monk E.V., Ferenc I.D., [57]
The duration of the financial cycle of the enterprise (calculation according to the formula)	TFC = TOC – – PO_{KZ}	TFC = TOC – – PO_{KZ}	TFC = TOC + + PO_{DZ} – – PO_{KZ}	TFC = TOC – – PO_{KZ}	TFC = TOC – – PO_{KZ}

* Compiled by the authors based on sources [49,51,55,57,58]

** where, TFC – is the duration of the financial cycle in days;

TOC – duration of the operating cycle in days;

PO_{DZ} – the average turnover period of current receivables, in days;

PO_{KZ} – is the average turnover period of current payables, in days.

Our study showed [46, p. 46-47] that in order to determine the turnover of funds invested in working capital, starting from the moment of repayment of accounts payable for the received production stocks, and ending with the collection of receivables for delivered finished products, it is necessary to determine the financial cycle of the enterprise [58, p. 307], i.e. the duration of the financial cycle (cash flow cycle) of an enterprise (TCC), which cannot be calculated without indicators characterizing the efficiency of the use of individual elements of current assets:

$$TFC = TOC + PO_{DZ} - PO_{KZ}, \quad (1)$$

$$TVC = POsm + POnzv + POgp, \quad (2)$$

where TVC is the duration of the enterprise's production cycle (inventories); POdz - period of turnover of receivables; POkz - accounts payable turnover period; POsm - period of turnover of raw materials, materials and other production stocks; POnzv - turnover period of work-in-progress; POgp - period of turnover of finished products.

One of the important stages of the analysis of current assets, which is of particular importance for the effective functioning of the enterprise, the attraction of investments and the development of activities, is the financial analysis of relative indicators that characterize the financial stability of the enterprise and the liquidity of its balance sheet, and for the calculation of which either the indicators of the turnover of current assets and own working capital (assets), or their learning elements in the practical activity of the enterprise (according to the methodology given [57] and calculated in Addendum D and E in Tables 8-10).

Our study confirmed [47] that the management of the current assets of the enterprise is not possible without such management tools as financial analysis,

management accounting and special purpose audit, which are based on the classical functions of management - analysis, accounting and control (Addendum F), and are not possible without effective planning and such a partial management function as monitoring. In our opinion, the financial analysis of the current assets of the enterprise and its elements is the first tool and ensures the effectiveness of the management process, as it determines the condition, efficiency of use, trends of changes, the influence of negative and positive factors for the application of such management tools as management accounting and special purpose audit. The need to apply management accounting at enterprises is confirmed by the fact that it has both an intra-economic and a strategic nature in economic entities for the implementation of a mechanism for managing their activities in the context of ensuring competitiveness and efficiency of their functioning. Our study showed [47] that the foreign practice of conducting audits confirms the need to use performance audits at enterprises - special purpose audits, where such audits are used quite widely, for example, for the management of the company's current assets. Monitoring is necessary for constant observation and operational management of the state and efficiency of use not only of individual elements of current assets, but also of all the activities of the enterprise and its results to ensure the efficiency of the enterprise and its competitiveness [47].

It is impossible not to agree with the study [59, p. 69-71], "that the influence of globalization processes, financial and economic crises, can become both threats and opportunities for the development of the national economy and its economic subjects..., and under different conditions, factors, actions and reactions to them on the part of the country's government, enterprises and their associations, both sectoral and inter-sectoral, threats can become both advantages of ensuring the competitiveness of the country's economy, industries and enterprises, and threats, and vice versa" (Fig. 2).

Therefore, military actions in Ukraine, as a threat to the functioning of the national economy and its subjects – enterprises, in our opinion, should also become the direction of economic transformation of their activities – enterprises and their associations. In the bottom aspect, agro-industrial complex and food industry enterprises have a competitive advantage – they operate even in periods of crisis to ensure the country's food and economic security, which is confirmed by the modern realities of the activities of such enterprises in 2022.

Research by scientists shows [60] that "the economic transformation of the national economy and its economic entities, as one of the structural components of restructuring, which is a process aimed at preserving the competitiveness and efficiency of all entities of the national economy, ensuring the formation of competitive advantages and further effective development without radical forms of transformation, significantly affects the directions of positive and effective development or corresponding changes in activity", has a strategic character and takes into account the aggressive influence of external environmental factors. Therefore, in order to choose a mechanism to ensure the functioning of agricultural and food industry enterprises, as well as other subjects of the economy of Ukraine, it is necessary to carry out an economic transformation of their activity, which has separate directions [60] (Fig. 3).

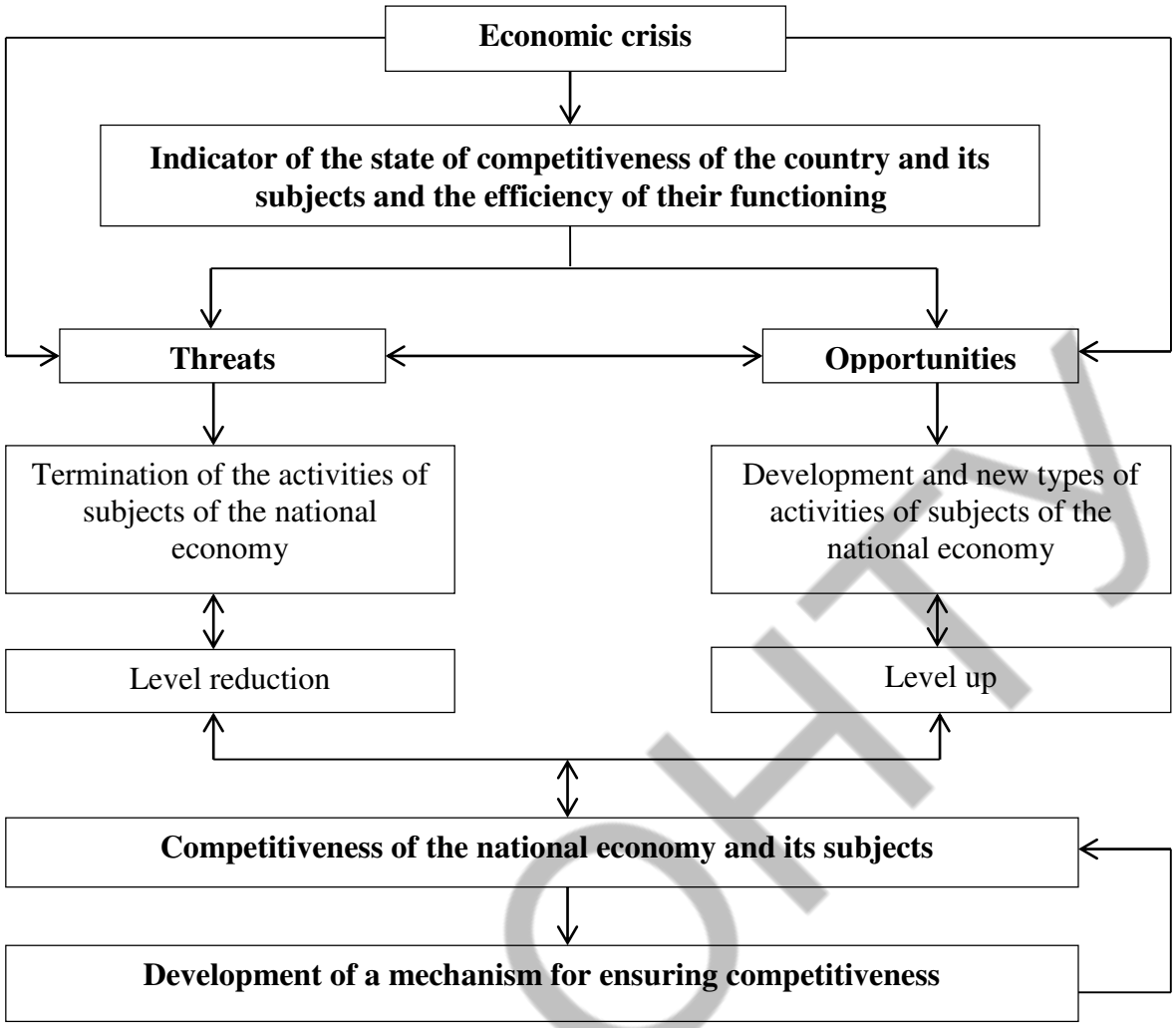

Fig. 2. The impact of the economic crisis and economic globalization processes on competitiveness of subjects of the national economy*

*Source: [59, p. 70]

This type of entrepreneurial (private) economic transformation of enterprise activity has a strategic nature of implementation and takes into account the aggressive influence of external environmental factors for their functioning, and has a degree of its implementation - soft, moderate and hard. One cannot but agree with the statement of the scientist [60] that soft transformation is the use of outsourcing tools to ensure the efficiency of the functioning of enterprises and the development of new types of activities, moderate is the formation of cluster associations or joining professional associations to protect enterprises to strengthen and preservation of the enterprise's activities, and rigid – joining for vertically integrated structures, for example, agro-holdings, in the event of a threat of termination of activity or absorption of the enterprise.

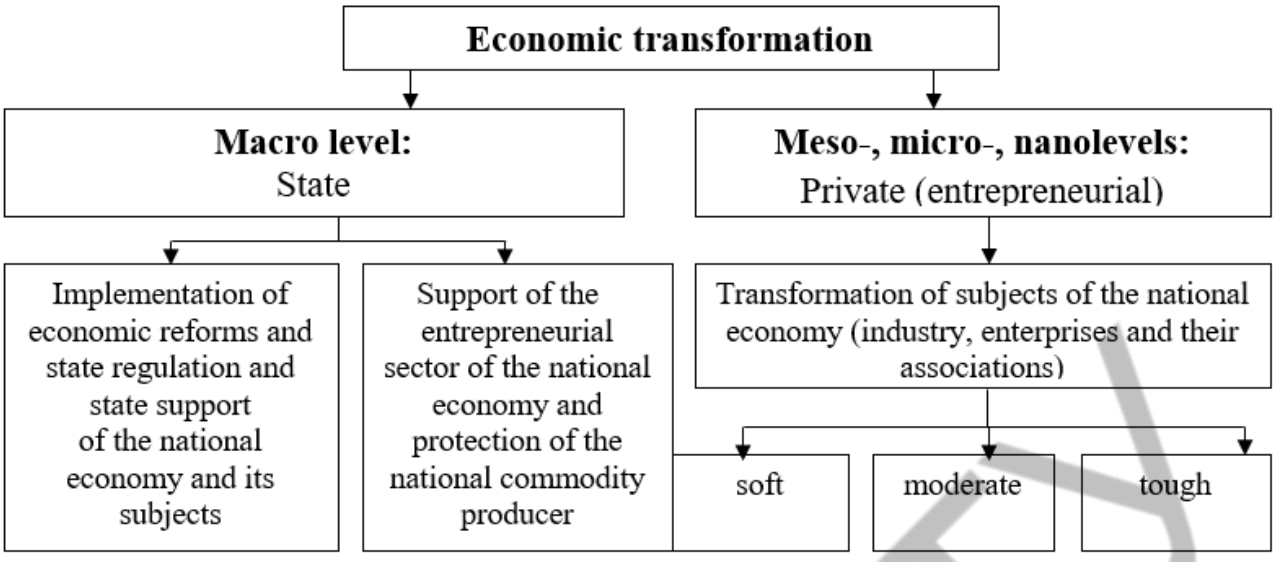

Fig. 3. Approach to the structuring of the conceptual and categorical apparatus "economic transformation" of the national economy depending on the level occurrence and purposes of its implementation*

*Source: [60, p. 397]

The economic transformation of the activities of enterprises is aimed at the preservation of already existing types of activities or their transformation in modern conditions, as well as the development of new types of their operational activities, which is relevant for the national economy of Ukraine and its subjects - enterprises and associations, which is the subject of further of our research.

V. CONCLUSIONS

The conducted research confirms the need to manage the current assets of the enterprise, in which the working capital is invested, in the modern conditions of the operation of the enterprise, which allowed to obtain certain results and draw the following conclusions:

– the current assets of enterprises, including industrial enterprises, have a large specific weight in the total assets and have a deficit of their own sources of financing, which negatively affects the financial condition of the enterprise and requires the search for management tools in the system of managing the activities of economic entities;

– effective management of the object of activity of any enterprise begins with a high-quality financial analysis, which forms its directions, the choice of tools and methods in connection with the identified negative and positive trends on the basis of the formed system of indicators, and the analysis of the state, structure, dynamics, the efficiency of using the current assets of the enterprise and its elements is impossible without such a management tool as financial analysis;

– in our opinion, the analysis of the use of current assets of the enterprise includes not only the analysis of the state, structure, dynamics, and efficiency of the use of the current assets of the enterprise as a whole, but also the analysis of the state, structure, and efficiency of the use of individual elements of current assets – stocks, receivables, cash and current financial investments, as well as the duration of the

company's financial cycle and the ratio of receivables and payables, the turnover of current assets and their elements, the profitability of current assets and its factor analysis, the analysis of the impact of the turnover of current assets on the liquidity and financial condition of the enterprise – our proposed comprehensive methodical approach to its implementation;

– the study of scientific publications and practical aspects of the activities of enterprises confirmed that, in our opinion, the calculation of the dynamics of the financial cycle of the enterprise and the financial analysis of relative indicators that characterize the financial stability of the enterprise and the liquidity of its balance sheet are important stages of the analysis of current assets, which is of particular importance for efficient functioning of the enterprise, attraction of investments and development of activities, and for the calculation of which either indicators of current assets and own working capital (assets) or their elements are used, calculated by us on the basis of data from two enterprises of the agricultural industry of Odesa region;

– the study of the publications of scientists confirmed that the management of the current assets of the enterprise is not possible without such management tools as financial analysis, management accounting and special purpose audit, which, in our opinion, are based on the classic management functions – analysis, accounting and control, and are not possible without effective planning and such a partial management function as monitoring;

– the conducted study of the works of scientists confirmed that the influence of globalization processes, financial and economic crises can become both threats and opportunities for the development of the national economy and its economic subjects, therefore, military actions in Ukraine as a threat to the functioning of the national economy and its sub entities – enterprises, in our opinion, should also become the direction of economic transformation of their activities – enterprises and their associations. And in this aspect, agribusiness and food industry enterprises have a competitive advantage – they operate even in periods of crisis to ensure the country's food and economic security, which is confirmed by the current realities of the activities of such enterprises in 2022. Therefore, in order to choose a mechanism to ensure the functioning of agricultural and food industry enterprises, as well as other subjects of the economy of Ukraine, it is necessary to conduct an economic transformation of their activities, which is a further direction of our research;

– the research results of this scientific work were published in 7 scientific papers, including 5 professional articles in the scientific journal "Economics of the Food Industry" (co-authored) and 2 theses of conferences (including 1 co-authored) and were approved at interuniversity and all-Ukrainian scientific student conferences at ONAKHT and ONTU in 2020-2022 and the IX International Scientific and Practical Conference "Economic and Social Aspects of the Development of Ukraine at the Beginning of the XXI Century" in 2021 [16,17,46,47,61,62, 63], and are also used in the practical activities of the food industry enterprise (certificate on implementation dated 12.26.2022 No. 05/27, Addendum G).

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OPTIMIZATION OF THE MANAGEMENT DECISION-MAKING SYSTEM AT A CONSTRUCTION ENTERPRISE

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Abstract. *Optimizing the managerial decision-making system at construction industry enterprises of Ukraine in present-day difficult economic conditions is one of the main factors critical not only for adjusting and improving the enterprise management system, but also for ensuring its stability and competitiveness. The results of the analysis of the essence of the process and ensuring the efficiency of managerial decision-making indicate that there is a large number of scientific opinions regarding the development of many theories and methods of achieving the required results in this area, but there is still no single generalized solution. The presented paper considers the theoretical aspects of optimizing the managerial decision-making. On the example of the construction company LLC Dongarantbud, the main factors that negatively affect the managerial decision-making system have been determined and analyzed. Relying on the opinion of many scientists to regard an organization as a single complex system and considering the financial possibilities for implementing changes in small and medium-sized enterprises, appropriate solutions for optimizing the managerial decision-making system, which are based on the reduction of negative factors influencing the effectiveness of decision-making, managerial decisions have been chosen. On the basis of the data obtained, a package of measures was formed, which in current realities is able to optimize the process of making management decisions at the construction enterprise LLC Dongarantbud and ensure its efficiency.*

Key words: *managerial decision, managerial decision-making process, management system, influence factor, optimization, efficiency of managerial decisions*

I. INTRODUCTION

One of the main components of the process of ensuring the effective functioning of an enterprise is managerial decision-making. Today, in connection with constant changes in the external environment and an increase in the number of negative factors that affect the company's activity, the process of making managerial decisions is complicated. Thus, unlike more ‘classical’ economic and financial crises, which the world community has so far been able to predict and choose countermeasure algorithms in advance, the crisis caused by a natural phenomenon such as the coronavirus disease (COVID-19) had unpredictable consequences. They significantly influenced the economy of Ukraine and the way the run business activities of many enterprises, including those in the construction sector. To stop the spread of the new virus, countries around the world were forced to choose a policy of unprecedented quarantine restrictions and lockdowns. Of course, the introduction of such measures caused a global economic recession. For the economy of Ukraine, these events became true trial. Particularly tough times have come for small and medium-sized businesses, which, because of insufficient stocks and working capital, were not only unable to operate due

to restrictions, but also were uncapable of fulfilling their obligations to their employees. This fate did not pass the construction industry enterprises, which, because of the character of the activities they are engaged in, could not perform work in the remote mode, since they are clearly linked to a particular construction site or construction object.

However, quarantine restrictions stimulated digital transformation and significantly influenced approaches to the system of performing many managerial processes both at enterprises and in the whole country. Currently, most businesses in Ukraine operate in conditions of uncertainty and instability. Yet, despite all the present hardship, the main areas of activity for enterprises in the construction industry remain to be:

- ensuring competitiveness in the market;
- creating optimum operational organizational structures;
- implementing an effective personnel policy management system;
- balancing and regulating collective relations;
- dealing with the issues of creating and maintaining a positive image.

Therefore, the development of ways to optimize managerial decision-making at an enterprise is an actual scientific problem and a necessary toolkit for enterprise managers.

The scientific value of the obtained research results is that, basing on the analysis, a set of measures was formed to increase the effectiveness of managerial decision-making in conditions of uncertainty, including the implementation at the enterprise of a unified electronic communication system - kanban. The results of the research on optimization of the managerial decision-making system have important practical meaning and will be used in the activities of LLC Dongarantbud to improve the efficiency of its management system and activities.

Article was published on the topic of the scientific work:

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II. ANALYTICAL ANALYSIS

A narrow circle of domestic and foreign scientists can be attributed to the study of problems and the development of ways to optimize the managerial decision-making system at enterprises of various industries. A significant contribution to the research of the processes of making efficient managerial decisions was made by such scientists as M. V. Borovyk, Yu. E. Petruna, F. I. Khmil, M. M. Shkilniak, L. Nalyvaiko, T. Symonenko, K. Uschapovskyi, Kostin Y. D., Batiuk B. B., Voronyi I. V., Degtiar A. O., Ponomarenko V. S., Minukhina S. V., Besedovskyi O. M., Chaban V. V. These authors considered various aspects of managerial decisions. At the same time, the issues of optimizing the managerial decision-making system still remain insufficiently resolved.

III. SUBJECT, OBJECT AND RESEARCH METHODS

The purpose of the scientific work is to study the factors that have a negative impact on the functioning of the managerial decision-making system on the example of the construction company LLC Dongarantbud and to develop a set of measures to ensure its optimization. According to the purpose of the study, the following tasks were set and solved: to identify and analyze the main factors affecting the managerial decision-making system; based on the information received, to formulate recommendations for the optimization of each of the factors affecting the managerial decision-making system at the enterprise LLC Dongarantbud.

The object of the study is managerial decisions.

The subject of the study is the theoretical, methodological and practical development of a package of measures to optimize the managerial decision-making system at the enterprise LLC Dongarantbud.

The following research methods were used in the work: logical generalization and analysis when studying literary sources on the research topic; vertical (or structural) analysis, horizontal (or trend) analysis when studying the company's reporting indicators, analysis of relative indicators (coefficients) when assessing the financial condition of the company, comparative analysis when studying the dynamics of financial condition indicators, SWOT analysis.

IV. RESULTS OF THE STUDY

In changing external environment, the main task facing present-day management is to make effective decisions that can ensure the stability of the enterprise, its current and future competitiveness. To ensure effective life activity, each construction organization defines goals, the achievement of which is determined by performing certain actions and implementing them in the required sequence, which is a way of solving individual and partial tasks. The future of the construction company depends on how justified, clear and coordinated the decisions will be. That is why the priority direction of construction organization management in conditions of uncertainty is the identification and systematization of factors that negatively affect the efficiency of managerial decision-making and the formation of a package of measures to optimize these processes [2].

Based on this advanced experience of scholars and scientists who studied the topic of the efficiency of managerial decision-making, we collected the main materials of informative search. During the search, the definition of the term ‘managerial decision’ proposed by the scientists was cited, and the results were collected and listed in Table 1.1.

Table 1.1 – Approaches to defining the ‘managerial decision’ term

Author	Concepts (comments, additions)
M. V. Borovyk	A managerial decision (as a process) is a search, grouping and analysis of the required information, development, approval and implementation of a managerial decision. A managerial decision (as a phenomenon) is an action plan, a resolution, a verbal or written order, etc. A managerial decision is a creative act of a management entity that determines the program of activities for the effective solution of an pending problem based on knowledge of the objective laws of the functioning of the system that is being managed and analysis of information about its condition. Thus, a managerial decision is a choice that a manager must make in order to fulfill the duties imposed by his position [5] A managerial decision (as a phenomenon) is an action plan, a decree, an oral or a written order etc. A managerial decision is a a creative act of a management entity that determines the team's activity program for the effective solution of an urgent problem based on knowledge of the objective laws of functioning of the system managed and analysis of information about its condition. Thus, a managerial decision is a choice that a manager is to make in order to execute the obligations arising from his position [5]
Yu. E. Petrunia	A managerial decision is the result of a choice of a course of action made by a management entity (body) aimed at solving a specific managerial issue [4]
M. M. Shkilniak	A managerial decision is the main form of manifestation of the manager's response to all economic and management processes taking place in the organization, the result of which is solving the issues of formation, functioning and development of the organization, the maximum approach to the goal set [2]
L. Nalyvaiko, T. Symonenko	A managerial decision is the result of a management entity choosing the best alternative aimed at solving a specific management problem. Since the managerial decision is formed in the process of choosing an alternative, it is a certain summary of management activities, the result of considerations and analysis of actions and intentions, conclusions, discussions, forecasts aimed at realizing the management goal [1]

Based on the above-stated notions, we have summarized and expressed our views on this issue. In our opinion, a ‘managerial decision’ is a product that represents a reaction of a person or a group of persons empowered to form it, to the request of the internal or external environment, which defines a certain problem that needs to be solved. The managerial decision is the result of the activities of the competent body, and represents the best option compared to all other alternatives.

After analyzing scientific studies, as well as the practices of Ukrainian enterprises, by performing a SWOT-analysis, we have highlighted the relevant factors influencing the managerial decision-making system for enterprises in the construction industry. [8]. The important selection criteria were indicators such as the possible rapidity of implementation of optimization measures and their economic basis. Thus,

we received a list of the following influence factors for the managerial decision-making system that needs to be optimized, namely:

- system factors (in terms of the enterprise organizational structure);
- human factor;
- the factor of communication and means of work.

System factors, as one of the main factors of influence on the managerial decision-making system, has constituent parts, which include: system's compliance, management mechanism and scientific organization of management work. The essence of the idea of systemic influence factors is based on the assertion that individual elements that are combined into a general system are able to endow it with new qualities, and vice versa, the formed system affects management objects, which significantly influences the efficiency of managerial decision-making [5].

The management mechanism, as a constituent part of system factors, in turn consists of the following components:

- management goal;
- management methods;
- management incentives;
- control levers;
- organizational structure of management.

When conducting the research, we shall focus on the organizational structure of the company LLC Dongarantbud and the interaction between its elements (Fig. 1.1).

It should be noted that the organizational structure is formed depending on the goals of the enterprise and the divisions required for this [1]. It is the units that perform the functions that make up the business processes of the enterprise. The analysis of the organizational structure of LLC Dongarantbud made it possible to conclude that it belongs to the linear type, because each division is subordinate to the director (the executive body of the Company, who is appointed to the position by the supreme management body - the general meeting of the sole member of the Company).

The main duties assigned to the director of the Company include the following: representing the company in all institutions and organizations, concluding contracts on behalf of the company, managing property, issuing decrees and orders for the company, hiring and dismissing employees, in accordance with labor legislation, applying incentive measures and imposing correspondent penalties [17].

With the existing management structure of the enterprise, the following are subordinate to the director: Executive Director, Chief Engineer, Chief accountant. To the Executive Director – the inspector of the HR Department, the lawyer, the estimator, and the construction facilities manager. To the chief engineer – the Occupational Safety and Health engineer, drivers-mechanics and foremen who perform their duties in accordance with the current legislation and job instructions approved by the company. Therefore, we see the presence of only one-channel interactions and the concentration of the entire complex of management functions and developing managerial activities in one management link.

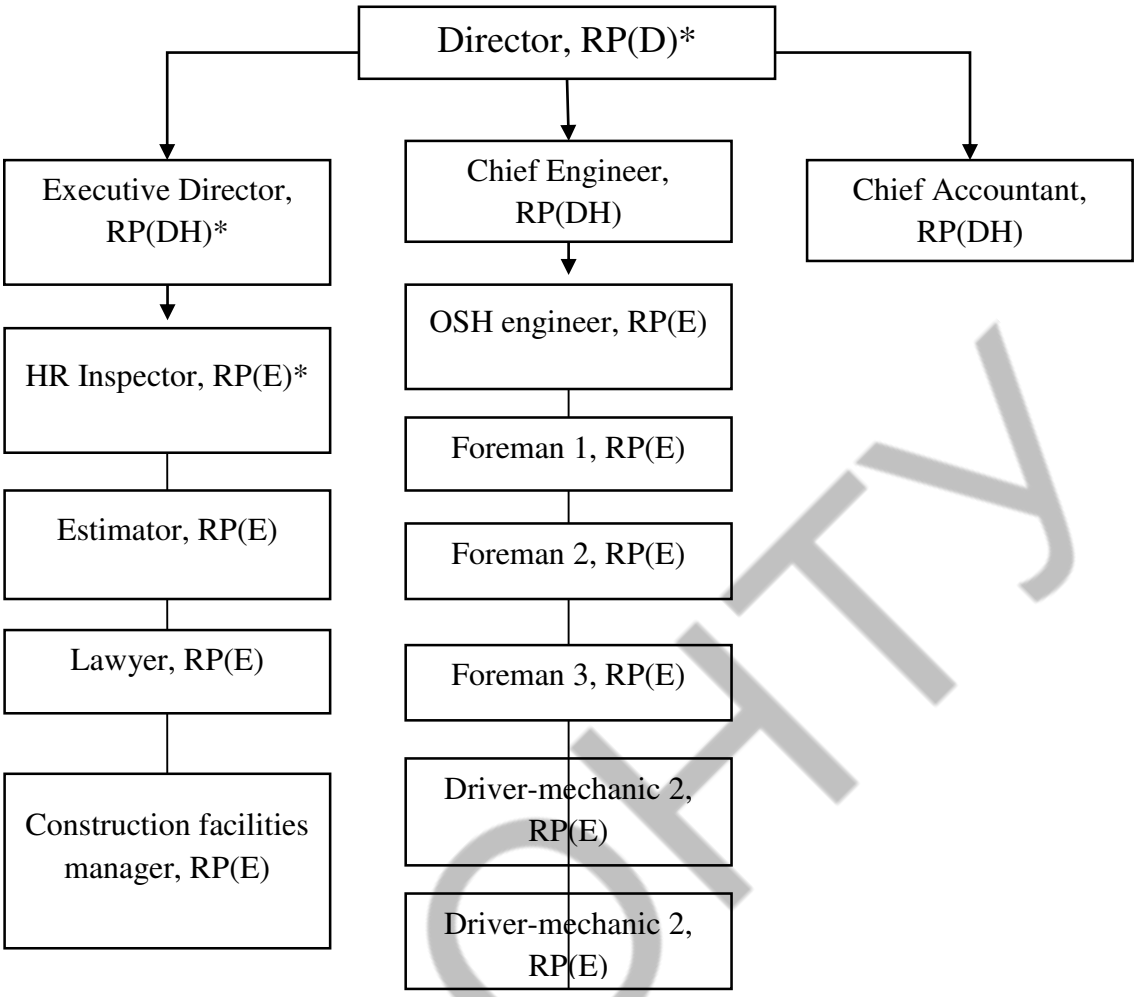

Fig.1.1 – The Organizational Structure of LLC Dongarantbud

The next influencing factor is the human factor. This is due to the fact that in the process of making and implementing managerial decisions at many enterprises, the main role is given to a person: executors of works, managers of various levels, heads. The question of their engagement in one or another process remains open. This, at first, depends on the scale of the organization and the management system structured in it.

For small construction enterprises, the basic complex of managerial decision-making can be divided into the following stages:

- identifying a problem and becoming aware of the need to solve it;
- developing and making a decision;
- implementing the decision at the enterprise (implementation) [3].

For the effective implementation of the managerial decision-making program, certain performers, specialists and managers of different levels should be engaged at each stage. The quality and rapidity of implementing correspondent decisions depends on their professional, spiritual and socio-psychological characteristics. Table 1.2 presents the process of making a managerial decision at the enterprise LLC Dongarantbud, according to the stage and phases it passes.

Table 1.2 – The Process of Managerial Decision-Making in LLC Dongarantbud

Stage I Identifying a problem and becoming aware of the need to solve it		
Stage of developing a MD	Responsible person/ group of persons	Decision-making person/group (DMP)
Identifying a problem	RP * (DH *; E*)	RP (D*; DH)
Formulating a problem	RP (DH; E)	RP (D; DH)
Setting goals	RP (DH; E)	RP (D; DH)
Defining assessment criteria	RP (DH; E)	RP (D; DH)
Stage II Developing and making a decision		
Alternative studies	RP (DH; E)	RP (D; DH)
Weighing up and processing alternatives	RP (DH; E)	RP (D; DH)
Rejecting irrational alternatives	RP (DH)	RP (D; DH)
Comparing alternatives	RP (DH)	RP (D; DH)
Developing and substantiating proposals	RP (DH;E)	RP (D; DH)
Modeling expected results	RP (DH)	RP (D; DH)
Reasonable choice of a rational decision	RP (DH)	RP (D; DH)
Stage III Implementing the decision at the enterprise (implementation)		
Organizing the decision implementation	RP (DH)	RP (DH)
Supporting and controlling the decision implementation	RP (DH)	RP (DH)
Feedback and correction	RP (DH; E)	RP (D; DH)

* RP (D; DH; E) – responsible person – an enterprise employee, who solves the assigned tasks, having the appropriate authority to do so and carries direct responsibility;

* Director – the director of the enterprise, according to LLC Dongarantbud, the director of the enterprise should be considered the first-level manager;

* DH – department heads, respectively, second-level managers. At the LLC Dongarantbud, the following should be considered Level II managers: the Executive Director, the Chief Engineer and the Chief Accountant;

* E – employees of LLC Dongarantbud (foremen).

The analysis of the managerial decision-making process gives a clear understanding that a generally collective system of engagement in solving problematic issues and achieving the set goals has been created at the LLC Dongarantbud enterprise [6]. Thus, as a rule, employees of all management levels are involved in developing managerial decisions (D; DH; E).

The next factor that should be paid attention to when optimizing the managerial decision-making system is the factor of having effective communications and means of work. We believe special attention should be given to the organization of the information structure and information support. At construction industry enterprises, as practice shows, a well-constructed system of communication channels through which

information flows circulate has a great influence on the efficiency of managerial decision-making [10]. The authors see the influence factor of means of work as the possibility of identifying reasons that have a negative effect on the performance of management processes and which should be optimized through the introduction of new means of automating the management process, the use of new technology, mechanization, software complexes or software support at the enterprise.

So, having analyzed the factors influencing the managerial decision-making system at the LLC Dongarantbud enterprise, we consider it expedient to optimize each of them (Table. 1.3).

Table 1.3 – The Directions of Optimizing the System of Managerial Decision-Making in LLC Dongarantbud [developed by the author]

Direction of Optimization	Recommendations on the implementation of measures
Optimization of system factors	Based on the results obtained after the analysis of the organizational structure of the enterprise LLC Dongarantbud and the interaction between its elements, the main recommendation is the transition to a mixed organizational structure - linear-functional. This will help to optimize communication channels and create conditions for the rational use of both vertical communications (command lines) and horizontal communications - cooperation of equal elements (communication lines).
Optimization of human factors	Based on the fact that a generally collective managerial decision-making system was created at the enterprise LLC Dongarantbud, the main recommendation for optimizing this factor is the implementation of programs for training and upgrading the enterprise employees' and managers' qualifications, including for the possibility to enable them to introduce new measures at the enterprise regarding the optimization of the managerial decision-making system. The goal of the implementation of the measure is to achieve a general, collective, optimal level of knowledge, which will allow making efficient managerial decisions and adapt to modern business standards.
Optimization of factors of effective communication and means of work	To optimize the factors of effective communication, it is necessary to introduce a document management and information exchange system at the enterprise, both in paper and electronic form. It should be an approved system with the same rules of use for all employees. To optimize the factors of means of work, to provide for the possibility of conducting work in remote mode, it is necessary to introduce a single electronic system of work organization and a combination of information flows, on the example of electronic kanban.

Thus, we created a package of measures to optimize the factors influencing the managerial decision-making system at the construction enterprise LLC Dongarantbud, which will provide for improving the quality and efficiency of operational management, appropriate to implement at other enterprises in the construction industry. For this purpose, a general scheme for optimizing management decisions at the enterprise is proposed (Fig 1.2). It has the following components: organizational, informational and controlling. Thanks to their successful operation, the enterprise will be able to increase the efficiency of management decisions.

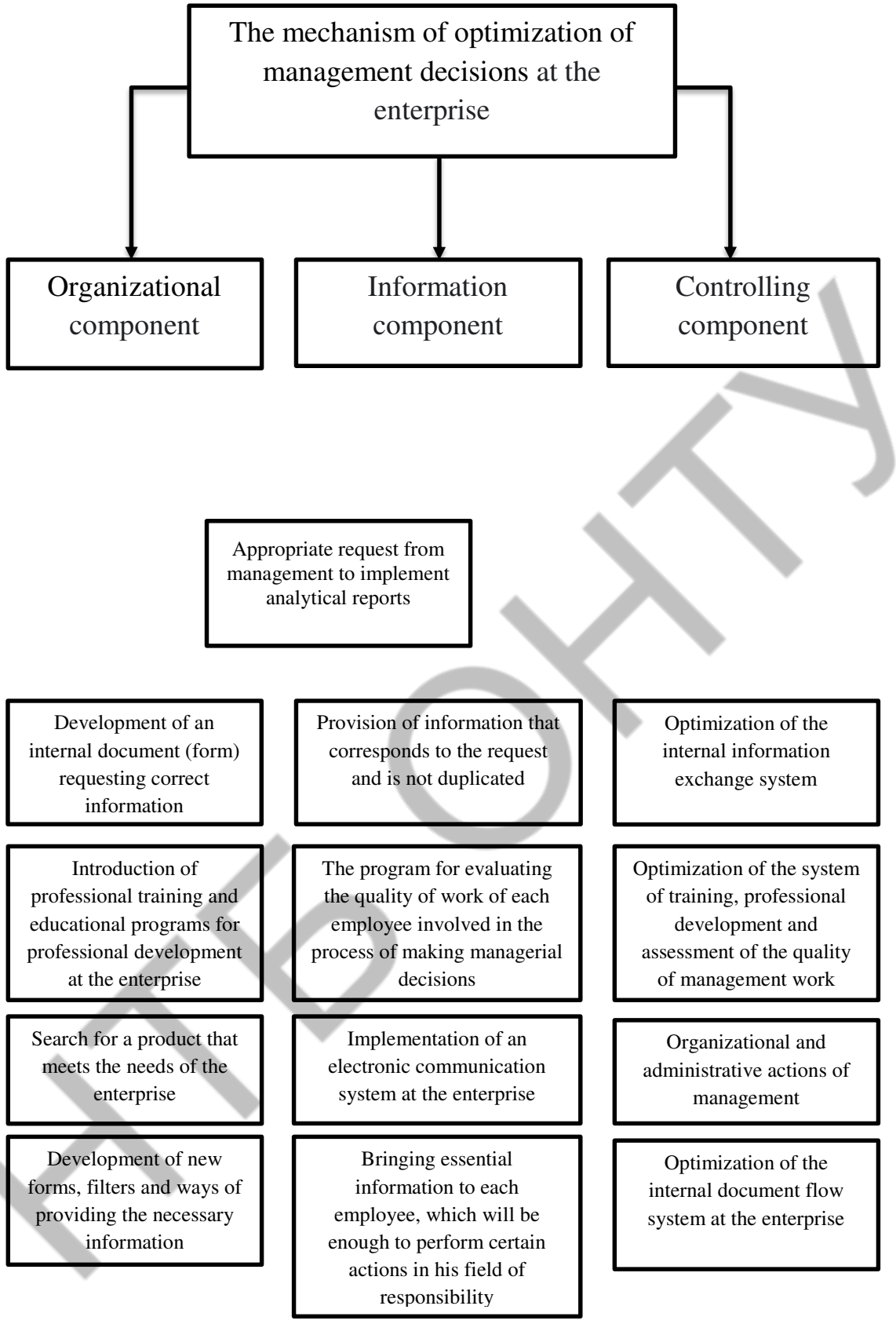

Fig. 1.2 – The mechanism of optimization of management decisions at the enterprise [developed by the author]

In our opinion, in the present-day period of remote management of a large number of work processes, special attention should be paid to the introduction of an electronic unified communication system between managers and employees at the enterprise, to enable rapid and clear setting of the tasks and monitoring their implementation. After all, communication plays a key role in enterprise management. Due to this, separate divisions are capable of solving various issues at different levels quickly. Sometimes the fate of an entire project can depend on efficiency. Thus, the above-mentioned issues were considered in more detail and our views on the communication links at construction industry enterprises in today's working conditions were formed. [20].

There are various theoretical and methodological approaches to defining the concept of communication. In terms of the topic the scientific paper dwells on, of course, it is about constructing such a communication system at the enterprise that allows developing, implementing and controlling managerial decisions effectively, both within the enterprise itself and for the purpose to receive feedback from partners and customers. It is a system that puts together information flows, makes an analysis and provides an opportunity to receive feedback. To solve the above-mentioned problems, the authors proposed to introduce an electronic kanban system at the enterprise LLC Dongarantbud.

The history of its creation dates back to the distant 70s of the previous century and takes it origin in Japan, then gradually spread around and, as of now, the kanban principles is implemented in enterprises all over the world. In fact, it is a system of organizing a continuous and flexible production flow. We want to note that depending on the functionality and types of enterprises, the kanban system can be implemented and adapted to any role and task. Now we shall analyze its essence, principles and goals in more detail.

The kanban system in today's digital format is a software or a software complex containing clearly defined tasks and a clearly organized work process, the purpose of which is to effectively achieve the goal set. In the context of the topic, the main direction that will be of interest to us is the paths a managerial decision goes through from the moment of its origin in the form of a problem (deviation of the system from ultimate indicators) to the moment of its implementation. It is the kanban that will help to monitor all stages and quickly make the necessary adjustments.

The principles of the system are based on the visualization of processes, which means that all tasks are added to the general plan and their status can be changed during the production process. Also, task grouping as a system principle is responsible for separating each task into ‘to do’, ‘doing’ and ‘done’, it is what helps to navigate in the productivity of organizational work. In the process of performing the task set, the manager will clearly see when it is not being performed for a long period of time (not enough attention is paid), or the work has stopped at some stage and needs additional intervention and assistance.

The main goals of the kanban system specific to construction industry enterprises (because each industry and company by introducing such a system follows its own, unique goal) include the following:

- ensuring the efficiency of managerial decision-making;

- minimizing warehouse stocks;
- flexibility and improving the efficiency of interaction between divisions, departments, managers, specialists and workers at different levels;
- openness of processes, which makes it possible to plan and strategically structure the activities of both separate units, managers, specialists, workers, and the enterprise as a whole;
- personal and system analysis;
- the possibility of rapid inclusion of third parties or their joining the work process;
- rapid identification of needs and response to specific requests [7].

Nowadays there is a lot of software that is generally aimed at solving the issues of systematization of business processes. The kanban system is intended to simplify communication between employees of different levels and save time, so that they can perform their direct duties. An example of such a product is CRM system (literally, it is Customer Relationship Management - a notion that covers the concepts used by companies to manage relationships with consumers, including the collection, storage and analysis of information about consumers, suppliers, partners and information about relationships between them), namely Bitrix24. With its help, you can create tasks and monitor their performance not only for a specific employee personally, but also for yourself and the department as a whole. Creating tasks is not a difficult undertaking. We shall now present several stages of problem setting.

At the first stage, it is necessary to enter the object with which work will be conducted into the system. The directions are different, they can be customers, clients, counterparties, partners and others (Fig. 1.3).

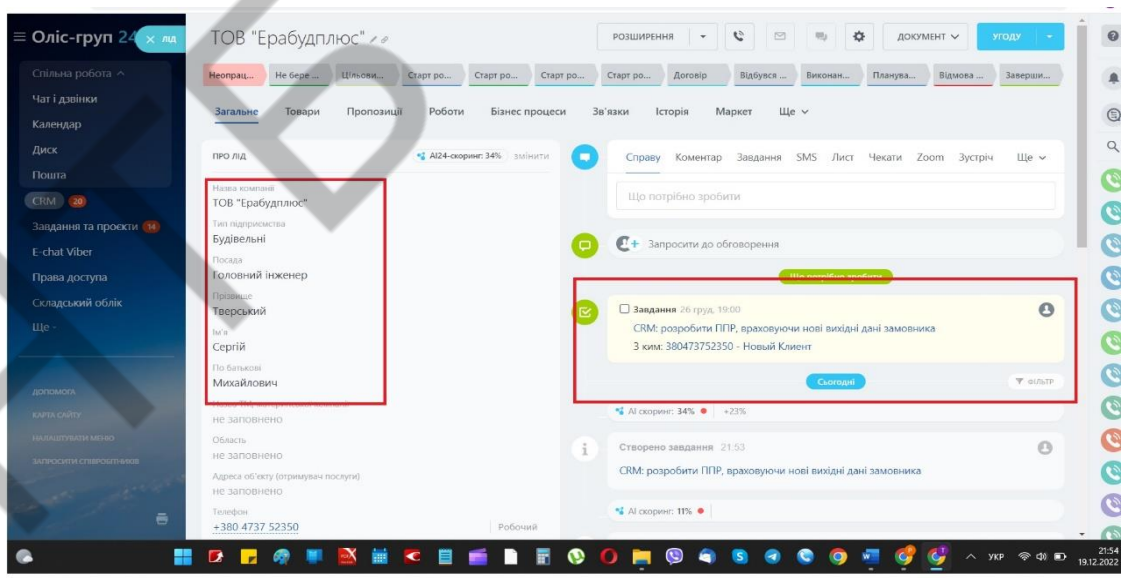

Fig. 1.3 – Entering information about the counterparty into the kanban system

At the second stage, you can start setting out specific tasks, which will display the person responsible for their implementation and deadlines: the beginning and the end of the task performance, which is shown on Fig. 1.4.

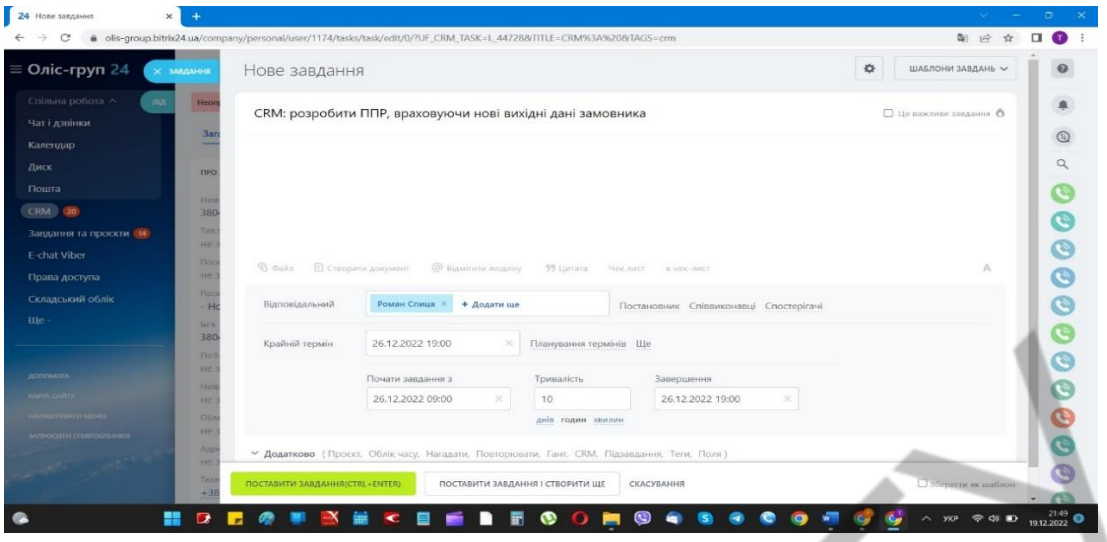

Fig. 1.4 – Assigning a task, the responsible person and the deadlines

When the task is set, the responsible person receives a message to the internal e-mail box, which is also duplicated in the program itself. After receiving the message (SMS), the responsible person confirms that he/she is familiar with all the conditions and confirms the start of the task performance. After completing the task, the responsible person gives feedback, and provides a finished product or other result of his/her activity, attaching it to the control panel. After that, the manager or the person who set the task receives a message confirming the completion of the task by the responsible person. The task stops glowing in a certain color, now the control panel looks like this (Fig. 1.5).

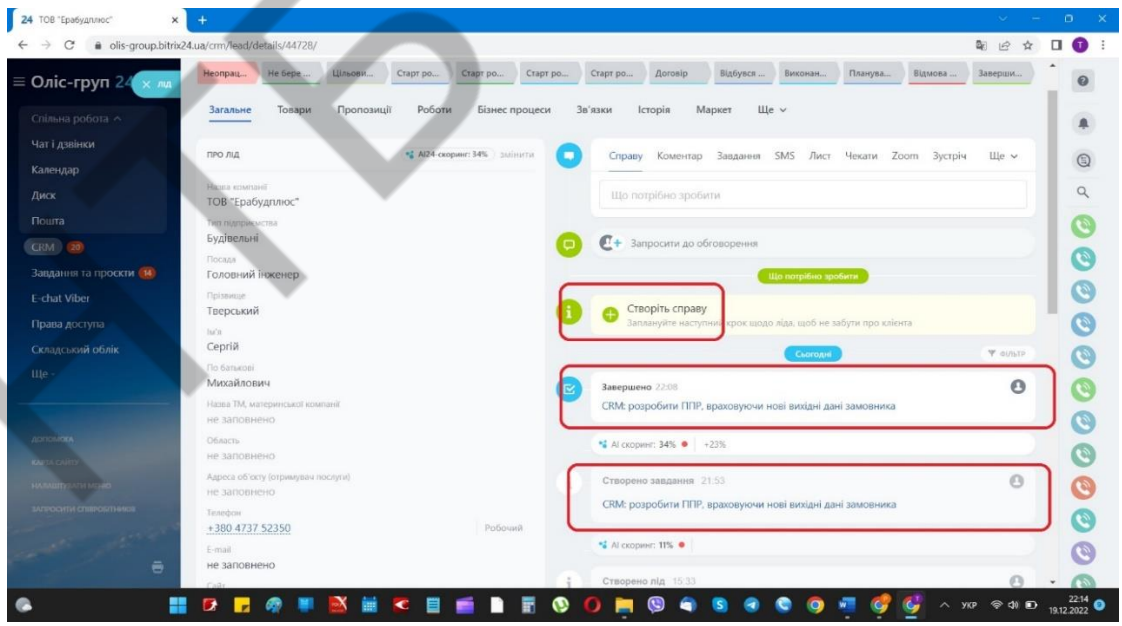

Fig 1.5 – Completion of the task

You can monitor the plan implementation process using analytics, which can be displayed in the form of charts, graphs, and other visualizations (Fig. 1.6). In general,

the program allows you to perform analysis on various indicators, both qualitative and quantitative.

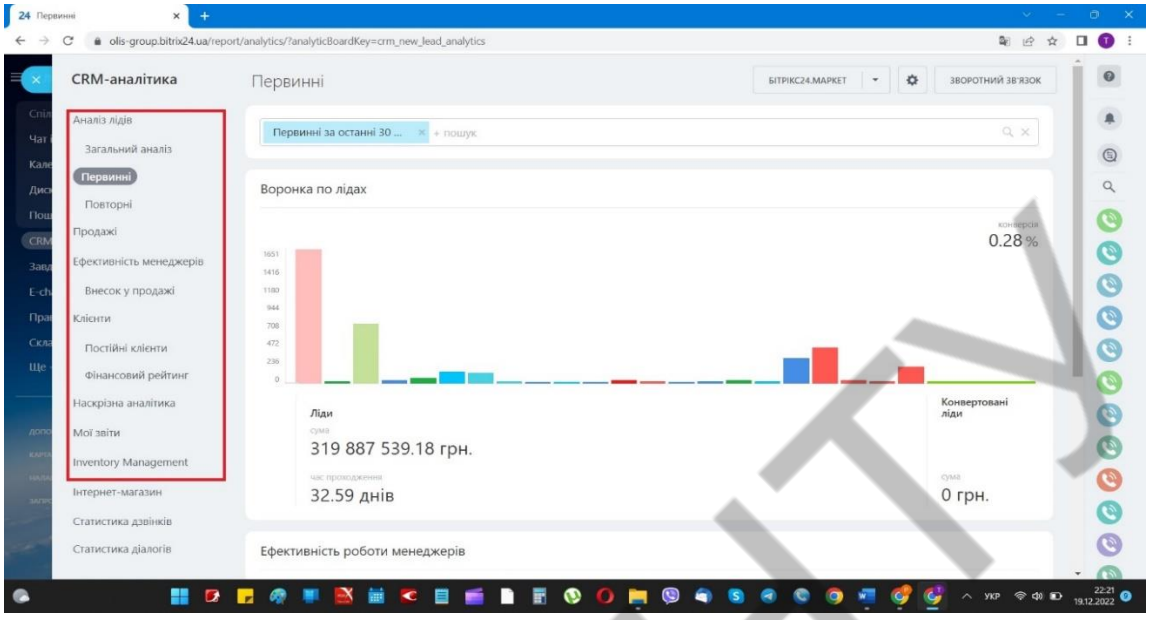

Fig 1.6 – Analytics of the workplan implementation

Analytics allows identifying weak points in structuring the processes important for the enterprise, for instance, to analyze the work aimed at implementing an efficient managerial decision-making system at the LLC Dongarantbud enterprise and other construction industry enterprises of Ukraine.

V. CONCLUSION

The optimization of the managerial decision-making is a complex and individual process for each enterprise. Considering the organization as a complex system consisting of various elements and connections, it is possible to identify a large number of factors that negatively affect its components. The performance of the enterprise management directly depends on the efficiency of the managerial decision-making system. For small and medium-sized construction enterprises, the simultaneous coverage and optimization of all influence factors is technically impossible, and economically irrational. The proposed set of directions for optimizing the components of the managerial decision-making system is formed from the following components: optimization of system factors, optimization of human factors, optimization of communication factors and means of work. Such a choice of optimization directions is recognized by the authors as optimal from an economic and technical points of view, as well as because of the possibility of rapid implementation and obtaining relevant results.

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FORENSIC AS A MODERN METHOD OF FIGHTING CORPORATE FRAUD

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Abstract. *The peculiarities of the spread of corporate fraud at Ukrainian enterprises are determined in the work, the urgency of introduction and popularization of the innovative method of forensics is outlined. The peculiarities of forensic procedure at enterprises for combating corporate fraud are determined. Modern forensic approaches to determining the risks of fraud are analyzed and innovative solutions are proposed to improve the methods of forensic procedures.*

Forensic is the most effective, modern method of combating corporate fraud, which acts not only ex post facto as a tool to investigate the facts of fraud, but also to prevent the occurrence of such facts. The main difference between forensics and auditing is the conduct of a larger-scale study, which includes not only financial and legal aspects, but also issues of information security.

The aim of the research is to analyze corporate fraud, its causes and structure in the domestic market, study and highlight the importance of using the method of forensics in combating corporate fraud, understanding the reasons for ineffectiveness of traditional methods and their differences with forensics, popularization of this method and widespread use by companies, which will help increase the economic security of enterprises, which will lead to increased profits, faster expansion and increase the level of international prestige of Ukraine.

Undoubtedly, the war in Ukraine imposes significant restrictions on the functioning of the internal audit, because the issue of the physical safety of employees has come to the fore. We hope that the process of rebuilding Ukraine is not far off. But foreign investors seek to receive guarantees regarding the targeted development of their funds, and this is where forensics will help.

Keywords: *forensic, financial fraud, economic crimes, audit, enterprise.*

I. INTRODUCTION

The economic and financial activities of enterprises are always subject to a number of internal and external risks. But internal risks are expressed by the most negative consequences from their occurrence. The most common internal risks are fraud by company employees who take advantage of the insecurity of internal security systems and act illegally. It is clear that such actions need to be fought and there are methods for this. But standard methods cannot always prevent fraud.

Even as the level of corporate fraud is on the rise, business owners and managers continue to perceive the cost of conducting fraud detection procedures as such, which exceeds the damage caused by employees

So, the relevance of studying the topic of corporate fraud and such an innovative method of dealing with it as forensic is related to an increase in the level of corporate

fraud for two reasons, the first is wartime in the state (managers are more focused on how to save the enterprise and employees), the second is the insufficiency of using traditional methods to resolving this issue.

II. LITERATURE ANALYSIS

2.1. CORPORATE FRAUD AND ITS STRUCTURE

At a time when domestic enterprises have more and more business processes, and the process of managing and controlling them has not yet been perfected, one of the main, most acute and urgent issues is corporate fraud. That's right, according to the annual report "Report to the nations 2020" from one of the world's largest associations of certified fraud investigators, it follows that the total amount of losses incurred by the company in 2020 as a result of corporate fraud reaches 3.6 billion dollars. The average damage caused by fraud for one company was $1.5 million, and the annual loss of profits was about 5 percent per enterprise [1, 35]. Fraud itself within companies, as of 2019, ranked 3rd in the business risk rating [2].

On the territory of our state, the situation is no better. Only 3% of respondents in Ukraine engaged an external forensic expert in connection with the most severe fraud case, compared to 20%. According to the PricewaterhouseCoopers Global Economic Crime and Fraud Survey 2020, about 51% of respondents in Ukraine suffered from fraud in the 24 months studied, 59% of fraud cases in Ukraine were committed by company employees, and only 59% of Ukrainian organizations investigated fraud. On average, one enterprise accounts for 2 to 5 incidents per survey respondent in the world [3].

Therefore, we can see that forensic as a method of combating corporate fraud has not yet received sufficient publicity and popularity in its application, and outdated methods of struggle have not been effective enough, so the disclosure of corporate fraud and the introduction of forensic are extremely important for every enterprise today.

First of all, it is important to note that there are two concepts for interpreting the concept of "corporate fraud": legal and general approaches. The legal approach is based on the definition of concepts through the prism of the laws of Ukraine, and the general one defines corporate fraud more broadly. Igor Shevtsov defines corporate fraud as the deliberate actions of employees, management or owners of a company related to the abuse of the trust granted to them for personal purposes and to the detriment of the interests of the company, that is, the author understands the concept of corporate fraud as an internal phenomenon [4]. On the contrary, Artem Kovbel defines corporate fraud as the actions of any third parties, not only personnel, that damage the company's business activities, that is, as an external phenomenon [5].

In accordance with the provisions of the International Standard on Auditing ISA (ISA) 240, fraud is an intentional act by one or more persons among management, management personnel, employees or third parties, which consists in the use of deception to obtain improper or illegal benefits [17].

The causes of fraud, according to Western experts, are three main factors, and if they intersect, then with a high probability there is a risk of fraud in the enterprise (Fig. 1.1).

The first factor is the incentive, which means that the person must have good reasons, incentives, or benefits from committing fraudulent acts. The next factor for committing various kinds of fraudulent activities is the possibility, that is, the enterprise must have such conditions (poor control methods, careless security service or problems in the management apparatus) that provide the subject with space to commit illegal actions. The third factor is the attitude, that is, the subject understands that his actions harm the company, and conducts consistent fraud.

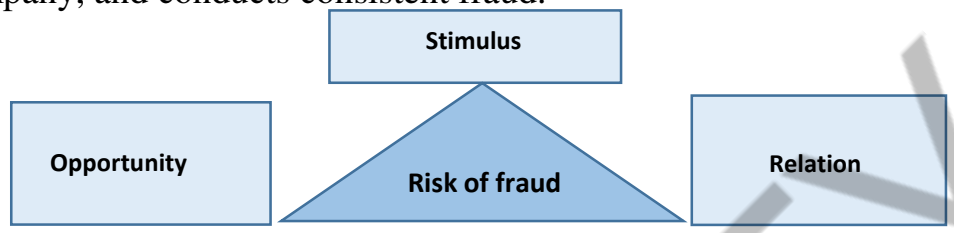

Fig. 1.1. Fraud Triangle

Source: [author's own development].

It is worth noting that Ukrainian companies, which today are not able to fight corporate fraud on their own, according to statistics from the study of the «YouControl» portal, six out of ten companies do not use any systems and programs to control and track possible risks. Almost half of the respondents either do not assess risks or conduct an informal assessment "by eye", 50% of companies maintain internal controls and strict adherence to procedures, and only 32% regularly train employees on company policies and operating procedures [6].

It should also be noted that companies with a large number of employees, according to a study conducted by Kreston GCG, faced fraud cases more often than companies with a smaller number of employees (Figure 1.2):

Fig. 1.2. Comparison of the level of fraud by the number of employees in the company

Source: compiled on the basis of a study conducted by the auditing company "Kreston GCG" [7, 35].

According to the report of the Association of Certified Fraud Investigators [8], the generalized portrait of the average fraudster looks like this: he is a man aged 34-48 years, a diligent employee with a higher education, who has been working in the company for quite a long time (at least 5 years) and takes one key positions in its structure and it is possible that such workers can simply be found more often in large companies, since the salary in such companies is higher, and the level of prospects and opportunities is better, which attracts diligent workers aged 34 and older.

Also, note that there is also a correlation between the level of fraud according to the company profile. Thus, regional companies have the lowest level of fraud, national companies have a slightly higher level of fraud, and international companies experience fraud cases more often (Figure 1.3):

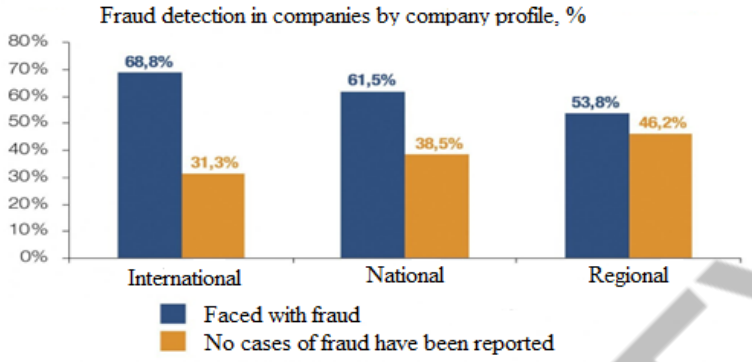

Fig. 1.3. Comparison of Fraud Rates by Company Profile

Source: compiled on the basis of a study conducted by the audit company "Kreston GCG" [7].

The level of corporate fraud is also increasing due to the fact that, according to statistics, before being caught, fraudsters manage to cause considerable damage several times to one company (Figure 1.4):

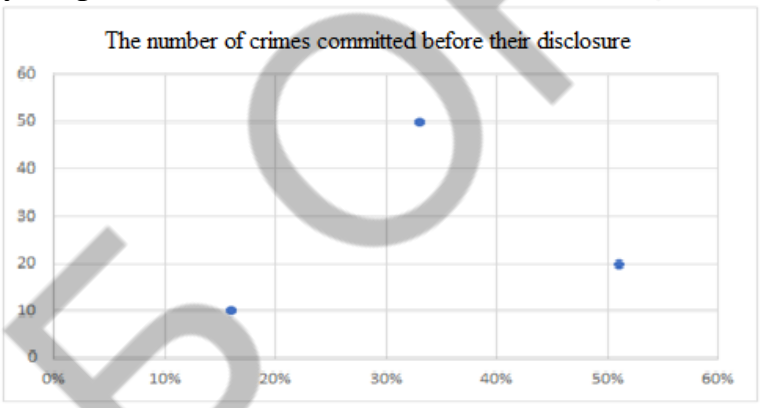

Fig. 1.4. The number of committed crimes in the field of corporate fraud before their disclosure [9].

Looking at the data, it's safe to say that businesses need to use better anti-fraud practices and use them on a regular basis. Corporate fraud also includes corruption and bribery, for example, commercial bribery, “kickbacks” in transactions, agreements on special overpricing or underpricing. By the way, in Ukraine, these two types of fraudulent activities are among the most risky for business. According to statistics from Transparency International for 2022, Ukraine ranked 122nd in the ranking of the most corrupt states, which also affects international relations and the reputation of our state, and in 2021, 117 out of 180 countries [8, 34].

For a better understanding of corporate fraud and its structure, it is also advisable to make a comparison with the proportion of corporate fraud types in Ukraine and the world.

Table 1.1. The structure of corporate fraud in Ukraine and the world in 2020

Types of fraud	The world average	Ukraine
Corruption	32	43
Billing	29	18
Check and paymeny tanpering	22	8
Expense reimbursements	21	11
Skimming	20	8
Cash on hand	20	14
Noncash	16	22
Financial statment fraud	16	7
Cash Latceny	14	9
Payroll	13	5
Register disbursements	3	2

Source: built on the basis of data [8].

It is also important to reveal the topic of the impact of digital technologies on the economic processes of an enterprise, namely, the threats of using such technologies for fraud in enterprises. In 2020, statistics showed that about 1120 leaks and cyber attacks were recorded in Ukraine [10]. Most often, Ukrainian enterprises attack consumer programs. Such programs are automatically installed on your computer when you click on an unfamiliar or insecure link or when you open a message in the mail. After that, the program begins to require money to return or not distribute certain information or return access to a computer device.

In the struggle, companies that do not have a built complex of protection against corporate hackers will not be able to effectively deal with such manifestations, so they should turn to specialists with many years of experience [11].

Here are the types of corporate fraud as a result of cyber attacks that affected enterprises in Ukraine (Fig. 1.5):

Fig. 1.5. Comparison of types of corporate frauds as a result of cyberattacks that affected enterprises in Ukraine [12].

So, summing up the description of the structure and analysis of corporate fraud in general, we can conclude that corporate fraud in Ukraine is flourishing and can lead to fatal consequences for business, to slow down the development of our state and to the loss of international prestige. It should be noted that on the territory of our state there are enterprises that maintain accounting and reporting inappropriately, primarily because of their own management interest in illegal enrichment. Corporate fraud is very common, and the fight against it is only gaining relevance from year to year.

Synthesizing the above facts into a single whole, we can conclude that the market needs new, innovative approaches to minimizing fraud in companies.

2.2. Theoretical foundations of forensics

A tool that innovatively combines all of the above methods is forensic. This tool has not yet been widely used in Ukraine, but has already proven itself well in Europe and the world. The modern concept - forensic, came into circulation quite recently, so it has not yet received an unambiguous definition. This concept comes from the Latin word forensic, which literally translates as public discussions.

If we consider the studies of scientists, then in order to fully disclose the definition of the concept of “forensic”, they should be separated into a separate table (Table. 2.1):

Table 2.1. Scientific approaches to the interpretation of the meaning of the concept of "forensics"

Author	The definition of "forensics" is...
Semets A.[14]	the process of studying the reporting and business operations of the company in order to develop measures to respond to fraud, manage it and prevent it on the basis of an expert judgment on the existence of facts (violations of current legislation by employees and management of the company; falsification of accounting and tax reports; cases of embezzlement or improper use of assets; corruption and abuse of authority; risk of fraud).
Doan M., Makki D. [15]	detailed analysis and study of the financial and economic activities of the organization, aimed at identifying illegal actions of employees or third parties related to encroachment on the financial resources of the organization.
Roik O. [16]	independent financial investigations conducted both internally and externally to identify financial risks or evidence of fraudulent activity on the part of company employees.
Rekhman A., Khashim F. [17]	a multidisciplinary industry that handles and disputes civil, criminal, economic and financial claims (business or personal) based on theories, methods and procedures of various fields (law, audit, accounting, finance, economics, psychology, sociology and criminology).

Source: summarized by the author based on [14-17].

After analyzing the author's definitions above, we can conclude that Doan M., Makki D. consider the concepts of forensics as an independent investigation, Rekhman A., Khashim F. as a complex of sciences, and Semets A. as a process. But some scientists liken the concept of "forensic" with identical concepts like a forensic audit or just an audit, so it is advisable to analyze and highlight the differences between forensic and audit, if only because most entrepreneurs do not have a full understanding of why order an audit every year.

The appointment of a forensic can be considered as measures to combat corruption, bribery, verify the virtue of counterparties, and simultaneously as measures to solve crimes, return lost funds, form an evidence base for representing the perpetrators in court, and also prevent future manifestations of fraud. Moreover, in the forensics of the method, there is no algorithm of actions that must be followed, which allows a wider analysis of the potential risks of fraud, the possibility of using any information and the ability to make assumptions. There is no doubt that forensic is more effective than an audit or inspection by law enforcement agencies of a business. Unlike the intervention of third parties before making decisions based on the results of

the audit, forensic allows the customer to make a choice regarding the use of the evidence and data collected. This can be either the usual dismissal of an employee, subject to the return of a significant part of the funds, or the filing of materials with the court.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The object of the study is corporate fraud and the most effective, innovative method of combating it - forensics.

The subject of the study is the theoretical work of foreign and domestic scientists, current legislative and regulatory acts, methodological provisions and instructions, the practice of applying the forensic method in the fight against corporate fraud.

IV. RESULTS

Since it is determined that corporate fraud must be fought with innovative methods, it is necessary to analyze and highlight the reasons why the use of individual methods is not enough to obtain an effective result, and enterprises need one integrated and innovative approach. To do this, we will determine the effectiveness of the use of methods that are now rapidly gaining popularity.

1) Security and control with the help of physical resources and building internal control systems are effective methods to prevent the occurrence of fraud risks;

2) Internal investigations - effective in case of small volumes of the enterprise and the impossibility of attracting specialists;

3) A sudden check is an effective method of obtaining truthful information about the state of affairs in an enterprise or company

4) Legendary verification is an effective method if you need to obtain comprehensive and reliable information about the state of affairs in an enterprise and is most effective in investigating fraud, since the primary source can indicate the methods of fraud and the persons who carried them out.

5) OSINT is an effective way if it is necessary to obtain information from open sources [13].

All of these methods of combating corporate fraud are not comprehensive, which, in turn, partially makes it impossible to effectively detect, investigate, and develop or improve existing control processes to minimize the risk of fraud in the future. One of the main differences between forensic and all other procedures is that forensic acts not only after the fact, but also acts to prevent the risk of corporate fraud. Therefore, under the condition of an independent “check-up” of the business through the forensic procedure, the entrepreneur is not only confident in the transparency of the investigation, but can also choose its goals, to which, accordingly, various methods will be applied, as well as maintain the company’s reputation and be able to solve the problem on one's own. That is, according to the forensic method, the algorithm may differ depending on what the verification is for.

Today, the use of the forensic tool in the fight against corporate fraud is innovative, it is not only the news of the forensic method itself, but also the fact that it uses modern approaches. Therefore, it is advisable to define and reveal the essence of innovative approaches to forensics.

Firstly, the innovativeness of the approach lies in the fact that forensic specialists are involved in the processing of the Big Data system, which allows them to search for the necessary information with advanced tools, use automatic search and thus quickly analyze large amounts of data, use automatic search with artificial intelligence capable of self-learning, identify a large number of facts and collect faster and better evidence. Restore damaged or deleted files and implement automated fraud detection systems.

Secondly, the innovativeness of the approach lies in the fact that forensic offers the use of compliance services. Compliance is an innovative line of business protection from corporate abuse. But so far, Ukrainian business, even if it uses compliance services, most often uses general guidelines for all employees. Forensic proposes to build internal documents in accordance with each category of employees separately, taking into account specific features [18].

Also, innovativeness in the use of forensic is manifested in the possibility of developing, implementing or improving cyber security systems, which makes it possible to prepare for possible attacks from modern viruses and the latest cybernetic fraud techniques. Fraud Investigation includes primarily financial investigation and corporate intelligence services. If financial investigations are focused on internal issues, then corporate intelligence is more likely to be responsible for external relations.Due diligence is one of the front-line services necessary for the economic security of the enterprise, which is included in the cohort of forensic services and allows you to check how potential risks can affect the expected result regarding investments, for example.

Forensic audit using the methods of performance audit, financial audit, investigative audit and correctness audit. Such an audit expresses an opinion about the facts of corporate fraud and damage, but requires an evidence base, which can be collected through the implementation of mechanisms included in the forensic service category. The relevance and uniqueness of forensic is also in the fact that after the investigation, forensic specialists provide support in court cases and represent the interests of the customer. And since the lion's share of unscrupulous employees are engaged in the appropriation of the assets of enterprises, it is important to dwell on the analysis of this aspect. In the rating system, the threat is considered as the activity of individuals or groups of individuals who can harm the company through their activities. Vulnerability is considered as criteria and features of assets, a product or type of service that attracts fraudsters to their appropriation or the sum of criteria that produce various risks for control activities in matters of economic security of enterprises. The consequences are seen as damages from the implementation of corporate fraud in the appropriation of assets to fraudsters that do not belong to them, but belong to the company. The cross section of the triangle is the basis for assessing the level of risk of fraud and the basis for analyzing the possibilities for recovering lost assets. Therefore, the first stage in the analysis of fraud in the misappropriation of enterprise assets by attackers is the stage of identifying risks and threats to the economic security of an enterprise, which should use various tools: fraud risk filtering, brainstorming, analysis of the nature, impact of threats and vulnerabilities, the impact of risks, analysis of leaks of priority mistakes.

Risk identification begins with the identification of ways and methods aimed at obtaining the assets of the enterprise illegally by malefactors. Weaknesses, which are threats of fraud risks, are simultaneously investigated, and suspicious financial transactions are monitored. Next, a study is made of the system for countering the theft of property, and the consequences for criminals in accordance with the law are also examined. After that, opportunities to collect evidence for criminal investigation of illegal actions are determined and the location of criminals and owners of embezzlement of company assets is established. The risk identification process is most often carried out in accordance with standard threats, but as technology evolves, it is advisable to constantly update and take into account the challenges and innovative fraud threats of today. Given the variety of risks, a holistic set of analytical measures should be used to strengthen protection, counteraction and facilitate the investigation of fraud. Summing up from this stage of the analysis, it should be noted that it is decisive in the development and implementation of analytical activities, and shows the prerequisites for the transition of standard counteraction and investigation of cases after the fact, to qualitatively innovative proactive protection and minimization of corporate fraud.

The next criterion of economic security is vulnerability, so the second stage of the analysis is the assessment of the risk of vulnerabilities of security systems and the assessment of the probability of its occurrence. First, a list of the main factors that contribute to the existence of vulnerabilities is determined, then the appropriate level of risk before the occurrence of fraud is established, then the assets are filtered in accordance with the risk of fraud before them, the machinations with which the fraud was committed are studied, and the guilty parties are identified. Based on the results of this stage, a report is formed, which indicates the list of potential points of vulnerability and what impact they may have on the assets, as well as what measures should be taken to eliminate the vulnerabilities.

The assessment of the risk of vulnerabilities for the economic security of the company is carried out in accordance with the identified risks and threats, as well as situational opportunities for fraud, carried out on the basis of the following methodology. The calculation method is based on the following indicators:

the general level of risk for which the calculation is made according to the formula:

$$3P_{Bk} = pH_{Bk} \times pB_{pП} \quad (4.1).$$

where PH_{Bk} – the level of consequences of the realization of a risk event;

$pB_{pП}$ – the level of probability of occurrence of a risk event;

the net level of risk, which is calculated according to the formula:

$$\text{УРвк} = \text{ЗРвк} * \text{Еіур} \quad (4.2).$$

where ЗРвк – general level of risk;

Еіур – effectiveness of risk prevention tools;

the efficiency factor of the risk assessment tools:

$$Kelp = \text{УНвк}/\text{ВУвк} \quad (4.3).$$

where УНвк – biased consequences of the implementation of a risk event;

ВУвк – costs of prevention of the consequences of the realization of a risky event.

And to assess the risk of misappropriation of assets, an expert assessment scale is used, reflected in (Table. 2.4).

Table 4.1. Scale of expert risk assessment [21]

Categories of tools	Scores
Low (the risk is more likely, but if it occurs, the consequences will be negligible)	1 - 3
Medium (the risk will probably occur, and the consequences of its onset will be medium)	4 - 6
High (the risk will definitely take place and the consequences of its occurrence will be high)	7 - 9

The last criterion in the triangle for assessing the economic security of enterprises for the appropriation of assets is the consequences of the influence of risks and threats. This assessment is based on: implementation of a structured, meaningful assessment of the vulnerability of identified threats to the economic security of the enterprise; collecting data on the economic, social, micro-sectoral consequences of the impact of identified risks and threats to the economic security of the enterprise; collecting data on the effectiveness and efficiency of mitigating measures taken to mitigate identified risks and threats to the economic security of the enterprise.

The analysis of the consequences of the impact of risks and threats is to identify the harm that can be caused or has already been caused to the enterprise in the event of each of them. The results of the conducted forensic analysis are formalized by the relevant documents, which indicate the security level of the enterprise for which the analysis was carried out. Such documents are provided to the customer in order to increase the level of security or return embezzled assets through fraud. The final stage of the analysis may be the procedure for applying punitive measures against guilty persons within the company to return funds, planning the stages of contacting law enforcement agencies and providing supporting documents about the damage caused to the company due to corporate fraud, studying reputational risks and developing recommendations for strengthening security to prevent dishonest actions workers.

Summing up the scientific study of the forensic business support model, it can be noted that such a model has four participants: the enterprise under study, the company providing forensic services, fraudsters and law enforcement agencies. And the model itself takes on the form reflected in (Addendum 1).

The use of the forensic model involves a number of problems with its implementation in practice, namely: lack of understanding by the owners of the enterprise of the importance of conducting forensic audits in the company and their attitude to such an audit as an inefficient use of funds; the confidence of the owners that their manager does not steal money and complete trust in the latter; lack of legal regulation of escort forensics; a wide range of various definitions of the concept of forensic, which leads to errors in the interpretation and understanding of the essence of this service. It is clear that for the effective implementation of the forensic method for widespread use, it is necessary to improve both the financial policy of the state and the forensic method itself. The improvement of the financial policy of the state, first of all, should be marked by the creation of a single forensic database on cases of fraud in the Ukrainian market. Such a base would provide Ukrainian enterprises with the

opportunity to exchange information on detected cases of fraud and schemes for their implementation, as well as ways to counter such cases and highlight the reasons and conditions that made it possible for fraudsters to act illegally. It is also advisable to focus on crime prevention by increasing the level of financial literacy of the population, popularizing forensic methods in the fight against corporate fraud and monitoring the market to identify new types of schemes and familiarize participants with them. It is also proposed to create the so-called "Black List of Fraudsters", which involves the inclusion of fraudsters or their accounts, and the reduction of bureaucratic procedures in conducting forensic. The last proposed step to improve the financial policy of the state in the field of introducing the forensic method and minimizing corporate fraud is the recognition and legislative consolidation of the concept of forensic in the Criminal Code of Ukraine, as well as making additions to ensure the evidence base collected in the process of forensic.

Methodological measures to improve the forensic method are: structuring and systematization of forensic methods for individual business areas; destandardization of forensic approaches to provide more opportunities for investigators; development of effective recommendations for assessing the risk of fraud; development of a system of criteria by which it will be possible to investigate the level of risk of fraud at the macroeconomic level. It is also important to separate such ways of improving the forensic method as strengthening international cooperation aimed at the rapid exchange of information, reducing bureaucratic procedures and mutual assistance in identifying and investigating corporate fraud.

As for the practice of applying the forensic method in the fight against corporate fraud, we consider it appropriate to cite several domestic cases, so we interviewed the co-founder of the international audit company Crowe, the senior partner of the «Vigilant Forensic Boutique» company, No. 1 forensist according to the magazine " Touch" – A. Kovbel. Artem spoke about a recent case of fraud by management in the Ukrainian subsidiary of the Swiss agricultural trader «Mimier Trade S.A.», which was disclosed thanks to his team. According to Artem, the company's financial statements were in good shape, «Mimier» was audited every year, and he could not identify deviations or irregularities on the part of the company's management. The trigger for concern was that contractors began to complain to owners about delays in payments for goods. Therefore, the owners ordered a forensic investigation procedure. Analyzing the data provided by Artem during the interview, we can summarize that according to the triangle of fraud, Yaroslav Gordienko, suspected of committing an offense, had an incentive in the form of benefits from committing a crime, namely, material assets that he bought with his company. Also, Y. Gordienko, had the opportunity to commit such a crime because of the position of the General Director and the complete trust and indiscretion on the part of the company's shareholders. The last factor of the triangle is the attitude, which in the case under study is manifested in the understanding of his misconduct by Yaroslav Gordienko, since he built the «Mimier» clone company and passed it off as a cash company, worked on the signatures of shareholders and financial statements of the company to minimize the risks of exposure. According to the forensics for assessing the economic security of enterprises, threats were identified in the enterprise under study in the form of the activities of the company's top

management with its head and coordinator Yaroslav Gordienko, vulnerabilities in the form of uncontrolled activities in matters of economic security by shareholders, and consequences in the form of losses of more than 5 million dollars. During the forensic period, we were involved in the processing of the Big Data system and used innovative approaches to automate the detection of fraudulent activities. After the forensic procedure, according to A. Kovbel, internal control systems were established and the introduction of a compliance system based on forensic analytics was recommended [22].

Summing up the research of this case, we can conclude that the audit did not reveal violations, while using forensic procedures, an effective investigation was carried out and the fraud scheme was exposed, the results were submitted to the court, and one of the persons involved was detained. The next domestic case of using the forensic method in the fight against corporate fraud is associated with one of the largest retail chains in Ukraine that does not want publicity. In the investigation of the fact of fraud, according to Artem Kovbel, corporate intelligence methods based on Big Data were applied, business processes, internal control systems, policies, regulations were analyzed, and management was interviewed. The company conducted proactive audits every year, but the data was distorted. As a result of the forensic procedure, the fraudulent scheme of the chief accountant was exposed in causing losses to the company by more than 22 million hryvnias by withdrawing money through non-commodity transactions to related persons registered with relatives. According to the triangle of fraud, all three sides of the triangle of fraud worked at once: opportunities, namely the system of internal controls, did not work according to the analysis of counterparties in tender purchases for coherence. Procurement was also not carried out according to the procedure. The motive for committing the crime was banal human greed. And the chief accountant, according to Artem Kovbel, found an excuse in the fact that as part of the implementation of work contracts, there was not a single fine from the regulatory authorities [23].

Summing up the research of this case, we can conclude that even conducting proactive, independent audits does not have the same effect in the fight against corporate fraud as forensic, due to the possibility of agreeing with the inspectors, since such an audit is carried out openly with responses to requests, in while forensic can be produced unnoticed by management.

V. CONCLUSIONS

In the conducted scientific work, a comprehensive study of forensic was carried out as the main and main, but at the same time - an innovative and newest method of combating corporate fraud as the most effective tool for detecting, investigating and preventing illegal actions against the company.

The following should be recognized as the result of the study: it has been established that one of the main constant threats to Ukrainian business is corporate fraud. Based on world experience and various Ukrainian cases of effective elimination of corporate fraud, the expediency of conducting and disseminating forensic procedures in domestic practice has been proved.

An interpretation of the basic determinants of the concept of "forensic" is presented, which allows Ukrainian business to better understand the complexity of this service. It has been proved that due to the constant improvement of corporate fraud methods, approaches to assessing the methods of combating it need to be modernized. Therefore, the latest system of criteria was defined for assessing the level of ensuring the economic security of enterprises from the most common types of fraud, the use of which will allow enterprises to more effectively plan their development strategy and effectively manage the impact of destabilizing factors. The effect of such criteria on the real case of the Ukrainian case of fraud on the assignment of assets is analyzed.

The study of cases of corporate fraud in the Ukrainian market and the analysis of the forensic method showed that all other methods used by enterprises to combat corporate fraud turned out to be ineffective compared to the forensic method. It is also proposed to establish the latest methodology for forensic compliance in enterprises to control and quickly respond to the risks and threats of corporate fraud. Popularization of forensic procedures will stabilize the Ukrainian economy and increase economic indicators at the state level, which, in turn, will reduce the level of fraud. The scientific novelty of the results obtained lies in the deepening of theoretical provisions and the improvement of methods for identifying the risks of corporate fraud and the method of conducting forensic. For the first time, it is proposed to structure and systematize methods and cases from forensic for certain business areas into an automated system based on artificial intelligence.

The practical significance of the results obtained lies in the possibility of their application in certain areas of business.

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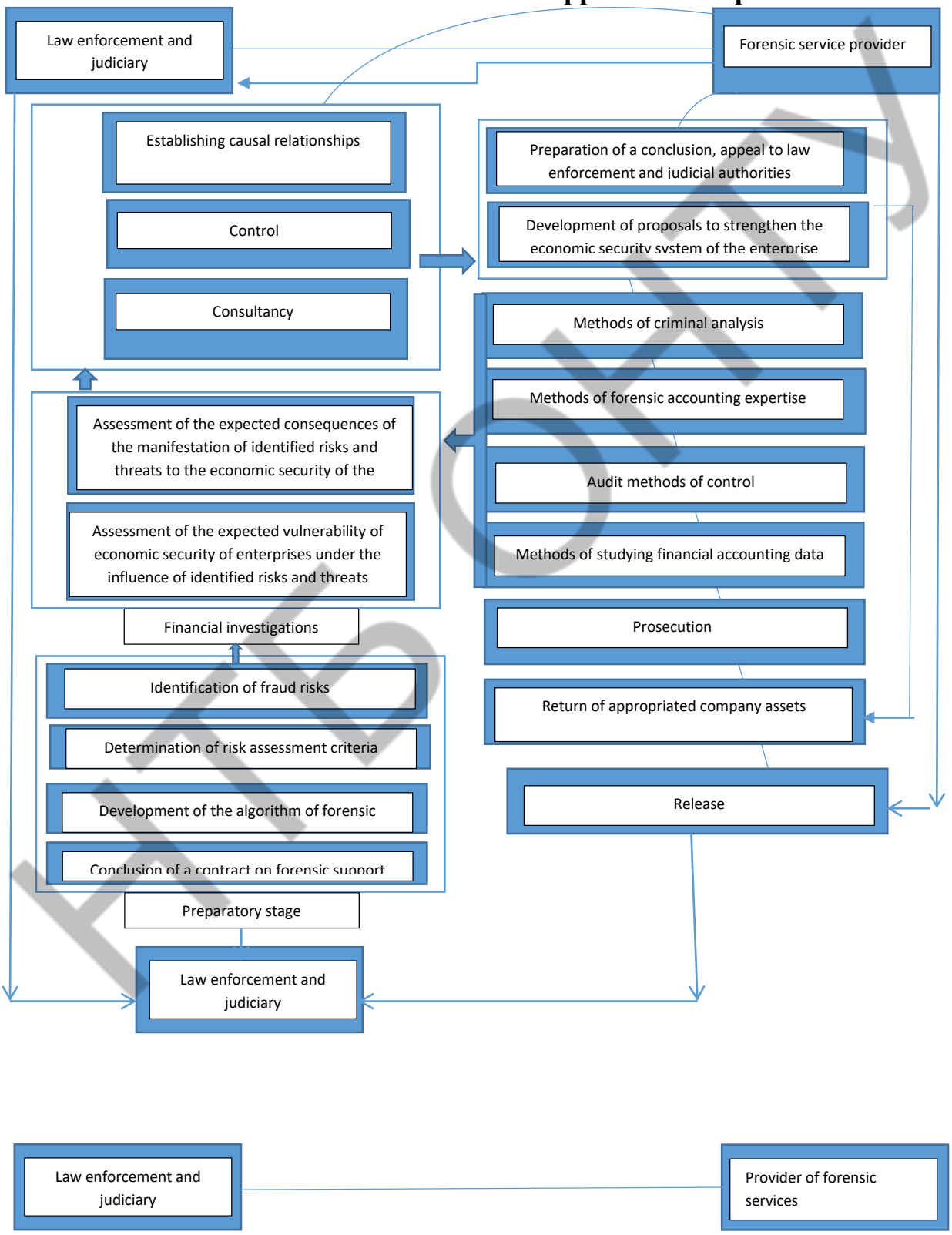
ADDENDUM 1

The model of forensic support of enterprises



ACCOUNTING FOR INNOVATIVE ACTIVITIES OF ENTERPRISES

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Abstract. *The development of business entities is possible only under the condition of constant updating of finished products and services. Accounting and analytical support of the innovation activity process is a time-consuming task due to the awareness of accounting procedures at each stage of innovation development. The aim of the scientific work is to improve the theoretical and methodological principles of accounting and analysis in the process of innovative activity of the enterprise. The essential characteristics of the process of accounting and analytical support of innovative activities of the enterprise are highlighted. The main provisions of the normative legal acts regarding the accounting support of innovative activities have been identified. The stages of development of design and estimate documentation were grouped. The entities that should carry out the examination of scientific and research works have been identified. The main stages of the life cycle of an innovative product and the tasks of each of them are highlighted. Methodological recommendations regarding the accounting display of the invention patenting process are of practical importance. An analysis of trends in innovative activity was carried out. An expert assessment was conducted to identify accounting and analysis problems based on a questionnaire with the involvement of accountants of leading enterprises in Volyn and scientists of higher education institutions. As a result, methodical recommendations on the accounting of innovative activity were formed, which were used in the practical activities of enterprises.*

Keywords: *innovative activity, innovative product, accounting and analytical support, patenting, innovation.*

I. INTRODUCTION

Innovation activity takes an important place in the functioning of the enterprise. In order to occupy a leading position in the market and prevent competitors from displacing their products, enterprises of any type of activity and all forms of ownership must continuously update, modernize, improve and develop.

The innovative sphere for Ukraine and domestic enterprises is not new, but there are still no clear instructions on how innovative developments are accounted for. In turn, this caused debate among many scientists regarding the display of research costs and identification of innovative development.

The main task of activating the innovative development of the enterprise is the formation of its information and accounting and analytical support, which should contribute to the expansion of opportunities for the formation and use of their innovative potential, which is why the work is relevant and timely.

II. LITERATURE ANALYSIS

Accounting is the activity related to collection, registration, generalization, accumulation, transfer of information to interested users. This explanation is given by the scientist Bondarchuk N. V [1]. Instead, another author, Pryadko V.V. [2], considers the concept of "accounting and analytical support" as a process of providing the management system with the necessary quality information. In our opinion, these two definitions complement each other, so accounting and analytical support should be considered as both a data collection system and as a process of bringing these data to management personnel.

The concept of "innovation" was first introduced by the Austrian scientist J. Schumpeter, who understood innovation as the creation of something new or the use of what is already known in a different way [3]. J. Shumper's scientific achievements served as an impetus for the study of the concept of "innovation" by other scientists. His ideas were developed and refined in various theories.

Representatives of the neoclassical theory of innovations (H. Mensch, B. Twiss, E. Rogers) consider innovation as an "impulse" of development caused by new production, new technology and methods. According to the theory of competitive advantages, an innovative product is considered as a way to achieve high competitiveness. Socio-psychological theory of innovation considers the defining role of the innovator as a carrier of innovative development.

We have identified the main provisions of regulatory legal acts regarding the accounting support of innovative activities (see Table 2.1).

Table 2. 1. Regulatory and legal provision of accounting for innovative activity

Regulatory document	Content
Economic Code of Ukraine	An innovative product is the result of the implementation of an innovative project and research and development of a new technology or product with the production of an experimental sample or experimental batch [4].
Law of Ukraine "On Innovative Activity"	Innovative activity is an activity aimed at the use and commercialization of the results of scientific research and development, which leads to the release of new competitive products on the market; innovative activity - activity aimed at the use and commercialization of the results of scientific research and development and causes the release of new competitive goods and services on the market; innovative product - the result of research and development that meets the requirements established by this Law; innovative products - new competitive goods or services that meet the requirements established by this Law [5].
Law of Ukraine "On Investment Activity"	Innovative activity is a set of measures aimed at the creation, implementation, distribution and implementation of innovations [6].

Note: systematized by the author

Such domestic scientists as: Ivanova O. [7], Krupka Ya. [11], Kulinych M., Safarova A. [8], Melnychuk I. [9] and others. Bondarchuk N. [1], Pryadko V.V. [10] devoted their works to the information provision of innovative activity. Despite a

significant number of scientific works, methodical recommendations regarding the accounting support of the process of developing an innovative product and analyzing the results of the implementation of innovations have not been sufficiently covered.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The purpose of this work is to develop a systematization of theoretical provisions and substantiation of practical recommendations regarding the accounting and analytical support of innovative activities of the enterprise.

To achieve the goal, the following tasks were set and solved: clarify the essence and deepen the theoretical foundations of accounting and analytical support of innovative activity; systematize accounting procedures at all stages of innovative activity; to analyze the state of the innovation sphere in Ukraine as a whole and the Volyn region in particular; identify and investigate innovation accounting problems;

The object of the research is the process of accounting and analytical support of the enterprise's innovative activity.

The subject of the research is theoretical, methodical and applied provisions on accounting and analytical support of innovative activity of the enterprise.

The methods of scientific research are the fundamental provisions of modern economic science, a set of general scientific and special methods of modern accounting and taxation, which are reflected in the works of foreign and domestic scientists. In the process of scientific research, the following methods were used: systematic approach; economic and statistical analysis; classical statistical methods; expert assessment; methods of analysis and synthesis.

IV. RESULTS

4.1. Theoretical principles of accounting for the process of developing an innovative product

Innovation is a product of intellectual activity, created as a result of research and development in any field of activity to increase competitive advantages, increase production efficiency, or to achieve another goal.

Objects and subjects of innovative activity, which for an accountant are objects of accounting, are represented in fig. 4.1.

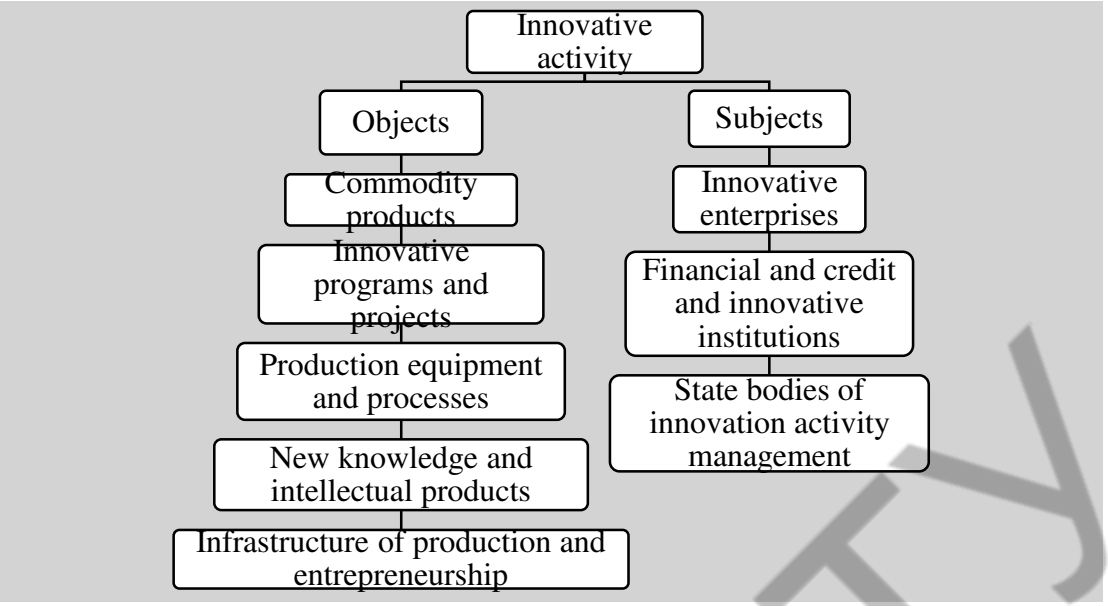


Fig. 4.1 Subjects and objects of innovative activity
Note: developed by the author based on the source [7].

The purpose of accounting for innovative activity is to create an information base for managing the processes of development, implementation and implementation of innovations at the enterprise, however, there are currently no methodological recommendations for accounting for costs, income and results of innovative activity.

The lack of clear instructions for the display of innovations led to the dispersion of development costs on different expense accounts.

We have identified accounting accounts that can be used in the process of developing innovations (see Figure 4.2).

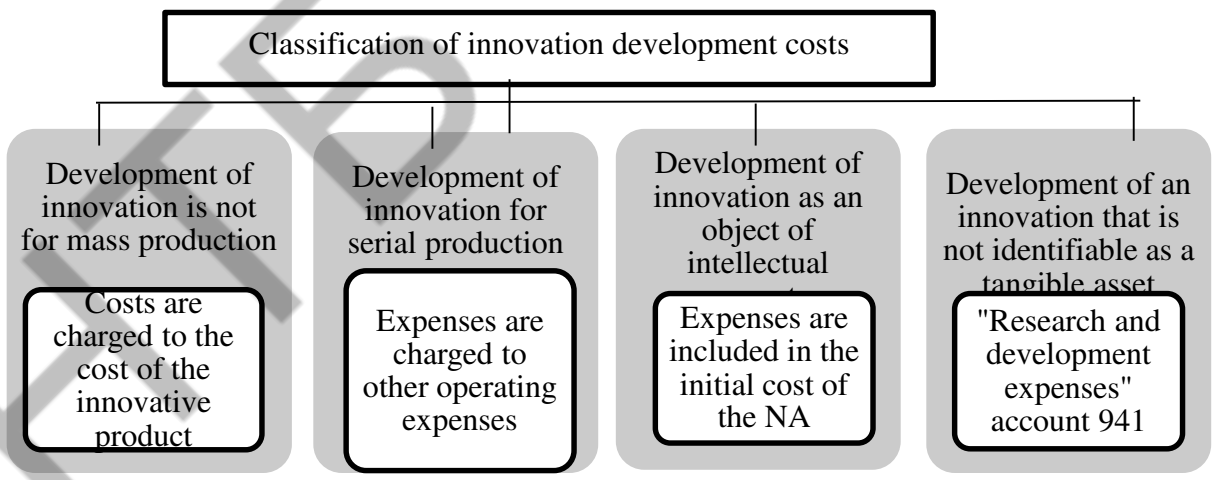


Fig. 4.2 Classification of innovation development costs
Note: formed by the author based on the analysis of sources [8;9]

Accordingly, for accounting of the production process, special accounts should be set aside to obtain specific information (see Fig. 4.3).

23 "Production "	26 "Finished products "	39 "Expenses of future periods"
• 23 "Producers of innovative products"	• 26 "Innovative products"	• 39 "Costs of future periods with the introduction of innovations"

Fig. 4.3 Proposed additional sub-accounts for accounting for innovations
Note: developed by the author based on the conducted research.

We have separated the typical implementation of the reflection in the accounting of the development of an innovative product (Table 4.1.).

Table 4.1. Typical implementations of mapping the development of an innovative product

№	The content of the business transaction	Correspondence	
		Dt	Kt
1.	Reflection of capital investments in the creation of a new object of fixed assets	152	20,23,661,65,131,685,631
	A new facility of fixed assets was put into operation	10	152
2	Reflecting capital investments in the creation of a new intangible asset	154	20,23,661,65, 131,685,631
	A new intangible asset was put into operation	12	154
3.	Production of new types of products, goods, services	23 941	20,22,661,65,13, 372,631,685
4.	Preparatory costs for creating an innovation are shown	39	20,22,661,65, 131,685
5.	The object of intellectual property was added to the company's charter	46	40
		12	46
6.	Expenses are written off to the cost price by means of estimated rates	23	39

Note: developed by the author based on the analysis of sources [11].

4.2 The content of accounting support at various stages of the development of an innovative product

The life cycle of an innovative product is identical to the life cycle of any product and goes through such stages as development, promotion to the market, growth, maturity and obsolescence. The life cycle of an innovation is the period from the birth of an idea to the production of a new product and its practical application. To start the innovation manufacturing process, financial sources are involved, which can be both own and borrowed. All costs associated with scientific development, adjustment, bringing to the desired state together constitute the investment process. According to the Law of Ukraine "On Investment Activity", innovative activity is defined as one of the forms of investment activity, therefore the stages of the life cycle of an innovative product are considered as an investment project [6]. When developing an innovative project, preparation of project documentation plays an important role. The components of the development of design and estimate documentation are presented in fig. 4.4 :

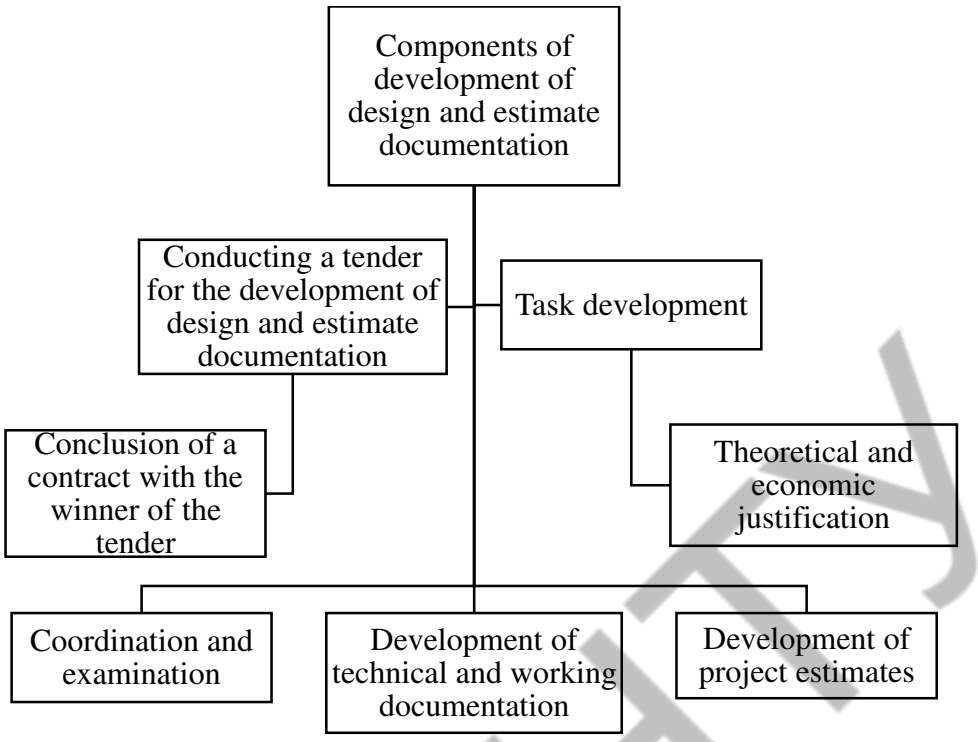


Fig. 4.4 Components of development of design and estimate documentation
Note: developed by the author based on the source [11].

The main legal document regulating the relationship between the customer and the organizer in the field of scientific and scientific and technical expertise is the contract for its implementation. The examination can be carried out by: bodies of executive power within their competence; enterprises, institutions and organizations of all forms of ownership, temporary creative collectives carrying out scientific and scientific and technical activities, specialized expert organizations; individual experts, groups of experts and expert councils. The stages of the life cycle of an innovative product are shown in Figure 4.5.

According to Figure 4.5, the following main stages of the life cycle of an innovative product can be followed:

I. Research papers. According to the contract, scientific research institutes of the National Academy of Sciences of Ukraine, branch Academy of Sciences and scientific divisions of educational institutions can carry out scientific research activities. At this stage, a contract for the performance of research work is signed.

II. Formation of the technical task. At this stage, the purpose of the research work is determined, the terms and order of the project implementation are established, funding sources are searched, the technical task is formed and the calendar plan of the scientific work is drawn up.

III. Research and development works. This stage involves the development of several product options and the formation of a sketch project (a brief description of the product to be created). A project estimate is also drawn up.

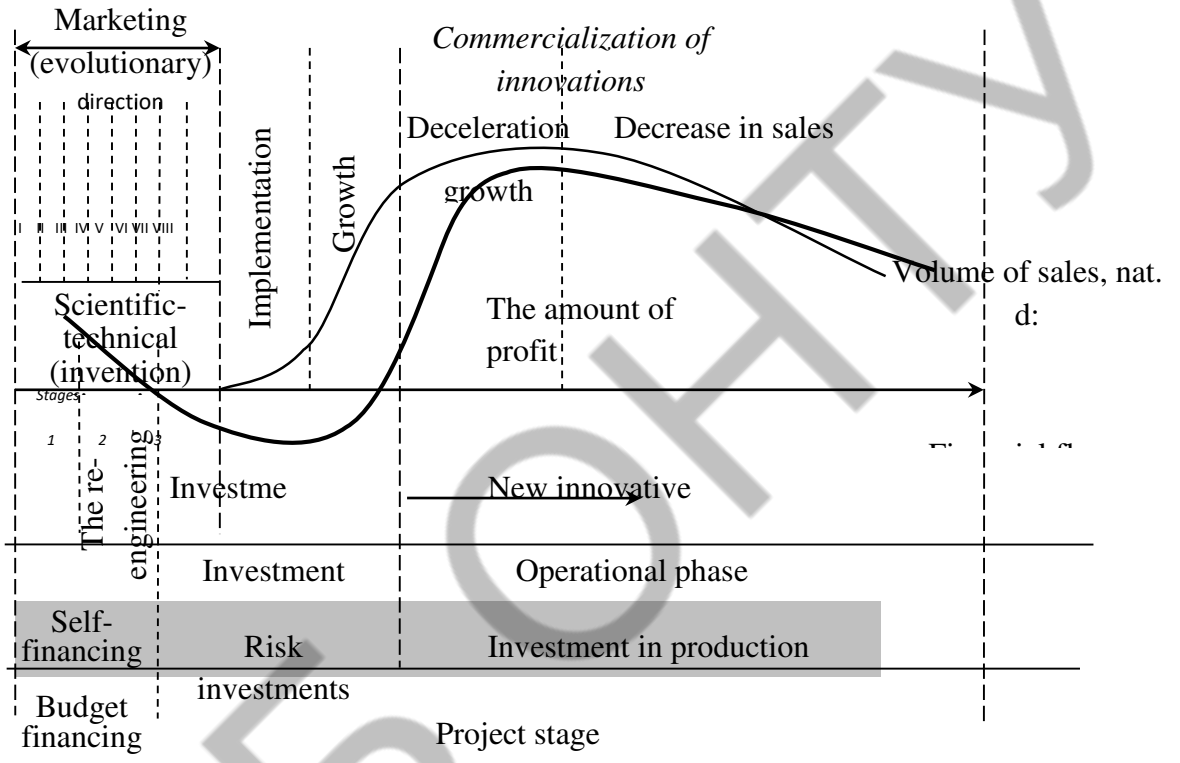
IV. Technological and organizational preparation of production. Organizational preparation involves a set of measures aimed at providing the production process with everything necessary.

V. Production. At this stage, the innovative product, which is accounted for on account 26 "Finished products", is written off from production to the warehouse according to the receiving-delivery invoice at cost price or wholesale prices.

VI. Realization of finished products. Costs for the promotion of innovative products to the market and other costs of a technological nature are attributed to costs related to sales.

VII. Operation. This stage involves servicing the sold goods.

VIII. Utilization. At this stage, products are written off after the expiry date.



1. Fundamental research
2. Applied research works
3. Research and development works

And Analysis of compliance of internal capabilities with external ones
II Generation of innovation ideas
III Selection of acceptable ideas
IV Development of the idea of a new product and its verification

V Market analysis and marketing strategy development
VI Assessment of the possibilities of achieving the goals of the marketing strategy
VII Development of a new product
VIII Testing in the market environment

Fig. 4.5 Stages of the life cycle of an innovative product
Note: source [12].

Features of innovative activity: uncertainty (it is quite difficult to predict the result both at a separate stage and for work in general, since the planned costs may increase during the beginning of the work); the possibility of multiple use of the results (the results of one study can be used in other spheres of activity); the difficulty of carrying out research and development; availability of highly qualified personnel; uniqueness and inimitability of the created product.

4.3 Accounting support for the development of an innovative product

Intangible assets are most likely to be borrowed during unfair competition. After developing an innovative product, it is important to patent it in time to protect the company from theft. A document that confirms the ownership of such objects as an invention and a utility model is called a patent. Only a natural person who is the author of the invention or an enterprise can register an object of intellectual property, provided that the invention is official. Order No. 2 of the Ministry of Education and Science of Ukraine dated January 22, 2001 provides for the procedure for drawing up and submitting an application for registration of an invention.

Patenting of innovative developments in Ukraine occurs with moderate activity. As of November 1, 2021, 631,033 objects of intellectual property have been registered since 1992: 129,568 inventions; 149,269 useful models; 44,475 industrial samples; 307,721 trademarks, taking into account split registrations. In particular, in 2020, the structure of issued patents is dominated by industrial designs - 60% of the total number of issued patents, inventions are in second place - 21%, the remaining 19% are utility models [13].

In the process of developing an invention and subsequent registration of ownership rights to it, all expenses that form the initial value of an intangible asset are collected on sub-account 154 "Purchase (creation) of intangible assets". When putting an intangible asset into operation, all accrued costs are written off by correspondence Dt 124 "Rights to objects of industrial property" - Ct 154. The main wiring during patenting is shown in table. 4.2.

Table 4.2. Basic postings when patenting an invention

Content of the operation	DT	CT
The services of a patent attorney are displayed	154	631
VAT is reflected as a tax credit	641	631
The fee for filing an invention application has been paid	154	311
The fee for the qualification examination of the invention application has been paid	154	311
The state fee for the issuance of a patent for an invention has been paid	154	311
The fee for publications on the issuance of a patent for an invention has been paid	154	311
Property rights to the invention are recognized and put into operation	124	154
Patent registration after commissioning		
Calculated amortization of the value of the invention rights (monthly)	23,91,92,93,94	133
The annual fee for maintaining the validity of the invention patent has been paid	39	311
The amount of the fee is written off to the expenses (monthly)	23,91,92,93,94	39

Note: developed by the author based on the analysis of the source [14].

Possessing a patent or certificate, the enterprise can transfer the rights to intellectual property objects or the right to use this object to another person, which are realized in the form of licenses. Methodological recommendations on the accounting of intangible assets state that a license is recognized as an intangible asset if its duration is more than one year, but less than one operating cycle. Scholars' opinions on this issue

differ somewhat: some argue that non-exclusive licenses should be accounted for as operating leases, and exclusive licenses as intangible assets, others are of the opinion that the cost of licenses should be included in enterprise costs [14].

If the licensee receives only the right to use the object of intellectual property, the record of the received license is kept outside the balance sheet, since its value cannot be reliably determined, in turn, the licensor keeps records on account 12 "Intangible assets". When purchasing exclusive rights, the object of intellectual property meets all the characteristics of an intangible asset.

As a result of the work, we have developed methodical recommendations for accounting for patents: the annual fee for patent maintenance is attributed to the expenses of the future period and written off quarterly to the account of the corresponding expenses of the period; the straight-line method is used to amortize the value of the patent, in particular, the term of useful use will be equal to the term of validity of the patent itself; the sale or purchase of goods is recorded on account 286 "Non-current assets and disposal groups held for sale"; payment for the use of the object of intellectual property, i.e. royalty is not subject to VAT.

4.4. Analysis of innovative activity within the national economy

According to the Global Innovation Index, in 2022 Ukraine ranked 57th out of 132 countries in the world. Compared to 2021, the country lost eight positions. Weaknesses of Ukraine are infrastructure, investments and political environment [15].

An important factor is the financing of innovation and investment activity. Most enterprises lack their own funds for new developments. Money from foreign and domestic investors is also coming in insufficient amounts. Enterprises receive funds from state and local budgets, although the main financing is carried out at the expense of own funds. In second place are other sources from which credit is most often chosen, followed by state budget funds.

The innovative activity of enterprises is revealed through the introduction of new technological processes and innovative types of products. In fig. 4.6 shows the trend towards a decrease in innovation-active enterprises. Since 2015, there has been a significant decrease in the number of industrial enterprises that introduced innovations by almost half. The situation remains fairly stable, but with minor fluctuations until 2020.

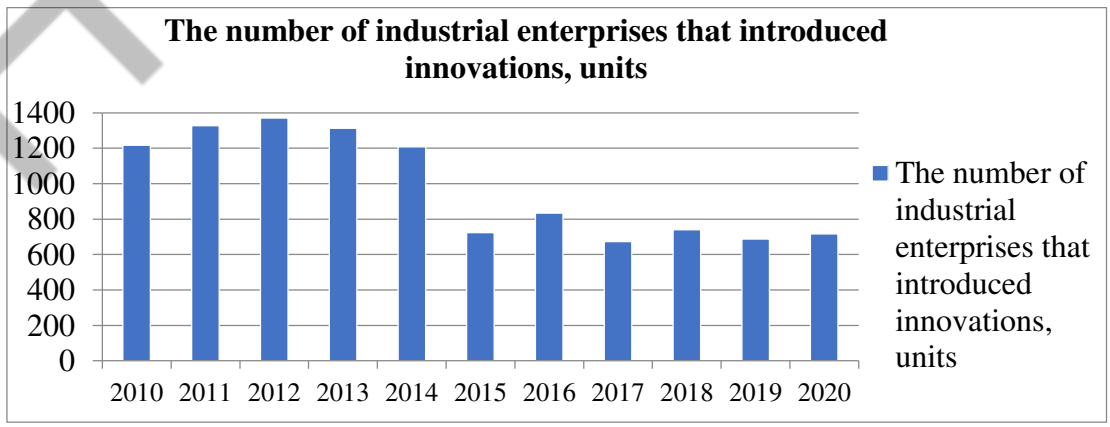


Fig. 4.6 Dynamics of enterprises implementing innovative activities
Note: developed based on source [13].

The trends of innovative activity in recent years indicate the existence of significant problems and a low level of development of innovative activity in Ukraine, which, in turn, negatively affects the competitiveness of products and the development of the national economy as a whole. The number of introduced innovations at industrial enterprises is shown in Figure 4.7.

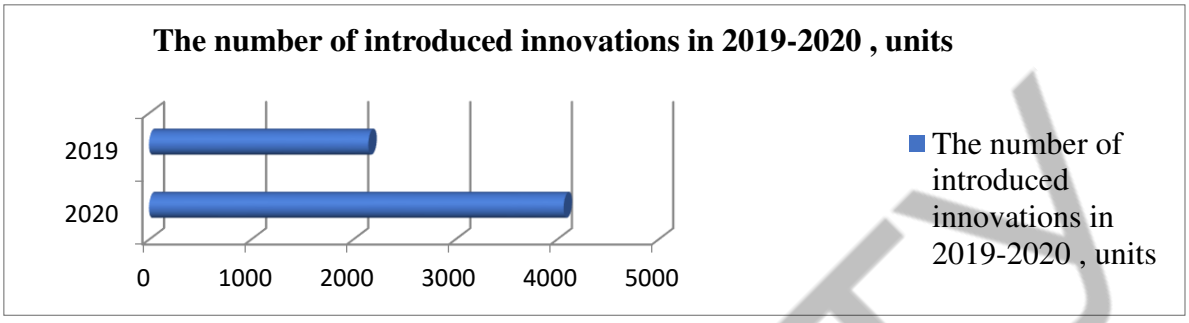


Fig. 4.7. The number of implemented innovations for 2019-2020
Note: developed based on source [13].

In 2019, 2,148 units of innovative products were introduced, of which 760 units were new machines, equipment and devices, and 2,318 units were new technological processes, of which 857 were low-waste and energy-saving. As we can see in fig. 2.4. in 2020, the volume of implemented innovations increased significantly, in particular by 1,918 units. or 89.3%. In turn, the situation regarding the implementation of innovations has significantly improved. In 2019, the volume of sold innovative products amounted to UAH 34,264.9 million, which is by UAH 13,261.3 million. less than in 2020.

An important indicator of the development of innovative activity is the number of scientific organizations and personnel. We will present the dynamics of changes in the number of persons conducting scientific research over the last period (Fig. 4.8). During 2017–2020, the number of scientists decreased by 13.41%, amounting to 7,965 people.

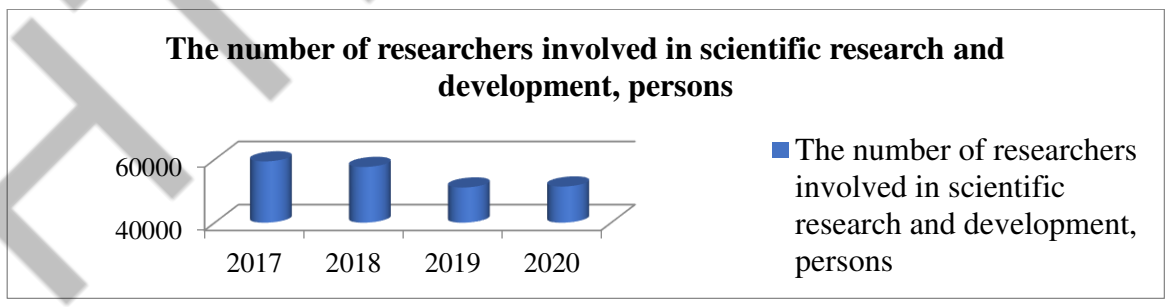


Fig. 4.8. Number of researchers involved in scientific research and development
Note: developed based on source [13].

In the age structure, the smallest number of researchers under the age of 25 and from 25-29 years, on the other hand, the largest number is at the age of 65 and over. It can be concluded that the younger generation is not interested in science and education, which in turn once again proves the expediency of state support for research in this direction.

The reasons for the decrease in the number of enterprises in the field of innovation may be: the imperfection of the legislative framework regarding the support of subjects of innovative activity; administrative barriers; illegal privatization of research institutions, uncontrolled transfer of intellectual property objects; decrease in the number of researchers and inventors; insufficiently provided conditions for inventive activity; insufficient level of state funding of scientific, technical and innovative activities; lack of a complete information base on innovative projects; weak material and technical base; employee dissatisfaction with the implementation of innovations; orientation of enterprises on quick payback; lack of conditions for creative work among employees.

The following ways of improving innovative activity in Ukraine can be identified: state support for innovative activity in strategically important types of economic activity; providing subsidies to high-tech and export-oriented types of economic activity; funding of research programs; stimulation of banks and non-bank financial and credit institutions to finance innovative projects; stimulating the development and support of startups.

4.5. Analysis of innovative activities of enterprises of the Volyn region

An important factor in the development of the region is the innovative activity of enterprises, which stimulates the expansion of the assortment and the release of updated products. More than half of the innovatively active enterprises are involved in the production of food products, the manufacture of wood products, the production of paper and printing, and mechanical engineering. According to the administrative-territorial division, 47.8% of innovatively active enterprises are located in the city of Lutsk, 17.4% - in the Lutsk district, 13% - in Horokhivskyi, 8.7% - in the city of Novovolynsk, 4.3% - in the Kovel, Ratniv and Rozhishche districts. The main areas of innovative activity are the development and implementation of new production processes. During the year, new technologies for the production of dairy products, children's clothing, plastic furniture and other vehicles were acquired, technological processes were implemented for the production of bread and bakery products, dairy products, paper products, shoes, decorative cosmetics, bearings, plastic toys, etc. [16].

The most innovatively active region of Ukraine is Kharkiv, followed by Kyiv and Dnipropetrovsk region. Volyn, Zakarpattia, Kherson, Khmelnytskyi, Chernivtsi, Luhansk, Zhytomyr, Mykolaiv and Chernihiv regions became outsiders. The rest of the regions are kept at an average level. In total, as of 2020, there are 1,007 enterprises in Ukraine that are actively developing or implementing an innovative product (Fig. 4.9).

Among the Volyn enterprises that most actively implemented innovations: LLC "Modern-Expo", "Production enterprise "Elektroservis". public joint-stock companies "SKF Ukraine", "Teremno-Hlib", "VHP", SE "Avtoskladnalii Zavod No. 1", JSC "AK "Bohdan Motors" and PrJSC "Terihem-Lutsk".

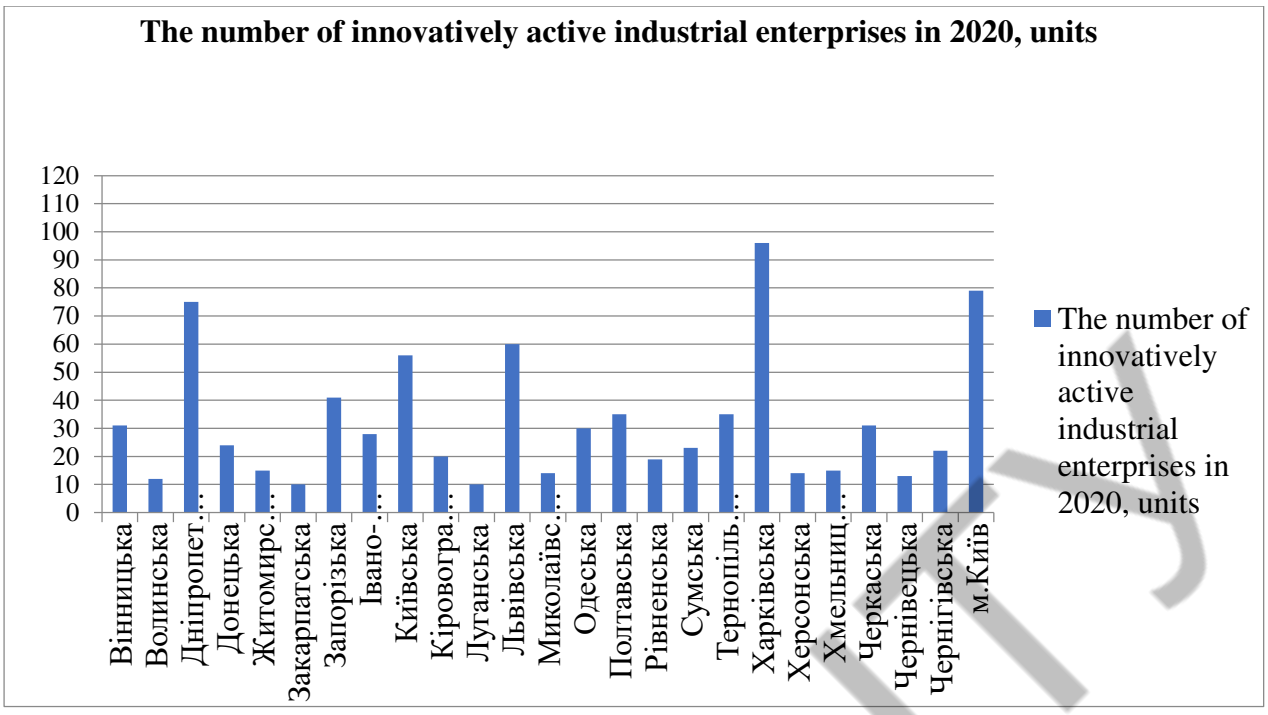


Fig. 4.9 Dynamics of innovation-active enterprises by region in 2020
Note: developed based on source [17].

In the Volyn region, the number of new technological processes put into production in 2020 is 10 units, of which 8 units are new or significantly improved low-waste, resource-saving technological processes. The number of types of innovative products introduced in the reporting year is 9, of which 5 are new types of machines and equipment. Also, in 2019, the share of enterprises in the Volyn region that implement innovations decreased from 15.1% to 10.4% (Fig. 4.10).

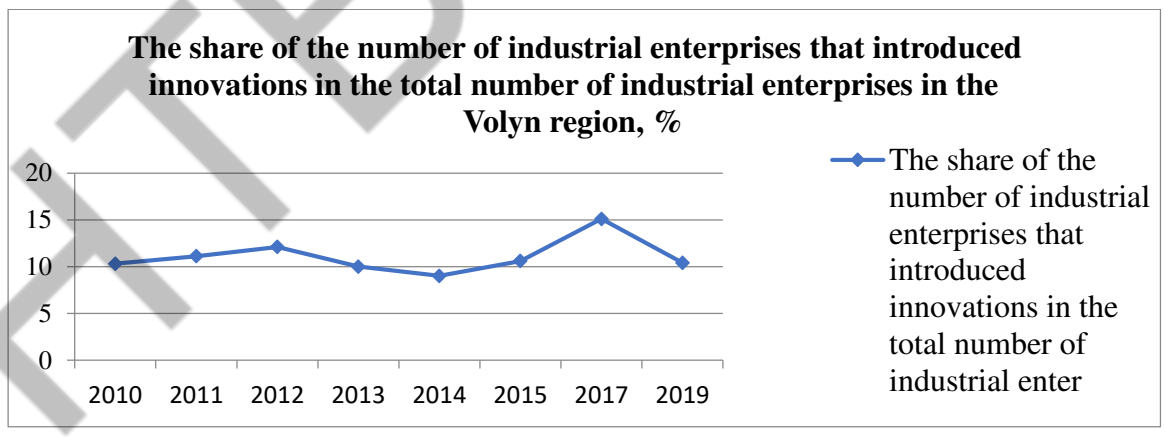


Fig. 4.10 Dynamics of the share of the number of industrial enterprises in Volyn that introduced innovations
Note: developed based on source [17].

In the Volyn region, the main reasons that restrain the development of the innovation sphere are: insufficient level of cooperation between enterprises and scientific organizations; undeveloped innovation infrastructure; high degree of depreciation of fixed assets; low solvency of consumers; dominance of industries with

a low level of raw material processing; insufficient level of commercialization of scientific and technical developments.

4.6. Identification of the issues of accounting of innovative activities of enterprises

In order to identify and systematize problems of accounting and analysis in the process of innovative activity of enterprises of the Volyn region, we carried out an expert assessment based on a questionnaire. Leading accountants and scientists from one of the higher education institutions acted as experts. As a result, a number of problems faced by the accountant when accounting for innovative activities were revealed.

Table 4.3. Results of expert evaluation

No	Survey criteria	Name of Company		
		LLC Kronospan YA	Terihem and Terihem Terwakovsky LLC	JV Modern-expo LLC
1.	The specifics of innovative activity	New innovative production of products with high added value, which will contribute to the substitution of oriented strand board (OSB) imports.	Introduction of new unique products to the market due to the use of innovative and energy-efficient equipment.	Innovative products for retail trade
2.	Innovative products have been introduced over the last year	Specialized energy-efficient equipment, including: - 45 MW biomass boiler; new transformer; new electric filter, which will provide an alternative solution for power supply and will reduce energy losses and dust emissions	Currently, a unique film with logos 6 microns thick (thickness of a human hair is 40 microns) is being produced for Euroruberoid on the order of companies from Switzerland. The company is the only one in Ukraine that produces such a film.	Smart shelves, self-service cash registers, POS equipment. Currently, developments are being carried out in the fields of Big Data, artificial intelligence and robotics
3.	Recommendations regarding the accounting support of innovative activity	Pay attention to the registration of innovations in the environmental sphere and adapt it in accordance with European accounting standards	Pay attention to the registration of expenses for the use of know-how and patents in accordance with the requirements of the European co-owners of the enterprise	Pay attention to the fact that the objects of accounting for innovative activity are not provided with appropriate accounting accounts

Note: systematized by the author

48% of respondents emphasize the problem of the lack of internal accounting registers, which can be used to monitor the indicators of innovative activity. 12% recognize that it is a problem that the objects of accounting for innovative activity are not provided with appropriate accounting accounts. 20% believe that general accounts without reflecting the specifics of innovation processes complicate accounting. The rest emphasize that there are no articles in the financial statements that reflect the income, expenses and results of innovative activities.

Having analyzed the problems of accounting for innovative activity and the activities of individual enterprises in Volyn, in order to improve the accounting of innovations, we consider it expedient to implement the following measures: introduce analytical accounts of accounting for innovations in order to increase the informativeness of innovative activity; to develop registers of internal accounting, containing specifics of the type of activity; to improve the methodological basis of innovation accounting in accordance with international standards.

V. CONCLUSIONS

1. The concept of "accounting and analytical support" was identified and the main theoretical principles of accounting and analysis of innovative activity were revealed.
2. We systematized and generalized the accounting procedures at all stages of innovative activity, namely, we focused on the primary documentation during the development of the innovation, taking into account the life cycle of the innovative product.
3. They analyzed the current state of the innovative sphere of Ukraine, namely, found out the main factors that hold back innovative development and gave recommendations for the activation of innovative activity.
4. The problems of accounting for innovations were identified as a result of an expert assessment based on a questionnaire of accountants of enterprises in Volyn.

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TERRITORIAL COMMUNITIES IN THE PROCESS OF MANAGING THE SUSTAINABLE DEVELOPMENT OF THE REGION

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Abstract. *It has been studied that the performance indicators of local budgets reflect the general socio-economic condition of the respective territory and its potential for sustainable development. After the decentralization reform, territorial communities received additional financial resources. It was determined that the availability of sufficient resources in local budgets is a guarantee that the territorial community has the opportunity to provide better and more diverse services to its residents, implement social and infrastructure projects, create conditions for the development of entrepreneurship, attract investment capital, develop local development programs and finance other measures to comprehensively improve the living conditions of community residents. It is noted that an important reform in terms of decentralization is land decentralization, since land is a resource that can be used by territorial communities to increase budget revenues. was determined that modern local development is a process of intellectual change of the local management system of the territorial community, the existence of a direct connection between the sustainable development of the territorial community and the region. The main tasks for territorial communities in the process of managing the sustainable development of the region are revealed.*

Key words: *financial decentralization, territorial community, decentralization reform, sustainable development of the region*

I. INTRODUCTION

The main strategic task of modernizing the system of state administration and territorial organization of power, which is being carried out today, is the formation of effective local self-government, the creation of comfortable living conditions for citizens, providing them with high-quality and affordable public services. Achieving these goals is impossible without the appropriate level of economic development of the respective territories, their financial support and sufficient sources to fill local budgets.

It is the financial aspect that is one of the most essential, on which, to a large extent, the success of the functioning of territorial communities depends. The presence of economically active business entities, a sufficient number of qualified labor resources, developed industrial and social infrastructure - all this and much more is the basis for the successful development of the community.

The result of the reform was an increase in the interest of local self-government bodies in increasing revenues to local budgets, finding reserves to fill them, and improving the efficiency of tax and fee administration. Affluent communities show high and dynamic growth rates of their own incomes. In terms of the use of funds, attention is focused on the need to form the most optimal structure of budget expenditures, to create an effective and not too numerous management apparatus, to

carry out a constant analysis of the spending of budget funds and to prevent cases of their irrational spending.

II. ANALYSIS OF LITERATURE

As noted in scientific studies, the development of any country in the context of globalization is increasingly under the influence of territorial economic concentration, which is characterized by the concentration of capital, labor, markets for goods and services, and information in a limited space.

Today, global trends in the development of the world economy have a significant impact on the development of all countries of the world and its regions, which is manifested in the opportunities for regions with highly competitive products to enter world markets, etc. At the same time, the experience of European countries proves positive results in changing the institutional systems of states, abandoning the vertical management system in favor of decentralized management systems, which contributes to the sustainable development of regions [1, p. 56].

Undoubtedly, the implementation of models of sustainable development of the regions of European countries without taking into account the institutional, political, economic, ecological and social features of the regional development of Ukraine will not contribute to obtaining positive results of sustainable development. This, in turn, requires the development of own models of sustainable development of regions with taking into account the existing circumstances and decentralization processes taking place in Ukraine today [2, p. 284; 3, p. 37].

However, taking into account the fact that institutional changes have already been completed, the decisive factors affecting the realization of the goals of sustainable development of the region, in our opinion, are and remain: political, economic, ecological and social.

Institutional and political factors were the basis in the process of carrying out decentralization reforms in Ukraine. The reason was the unsatisfactory ability of the vast majority of local self-government bodies to exercise their own and delegated powers at the appropriate level [4].

III. OBJECT, SUBJECT AND METHODS OF RESEARCH

The object of the study is the Territorial communities and their influence on the management of sustainable development of the region.

The subject of the research is the The process of managing the sustainable development of the region in conditions of decentralization.

Research methods: To achieve the goal and perform the tasks in the work used a number of general and special methods, namely: the method of analysis and synthesis; observation and generalization; causal; ordering; comparison; graphic methods; methods of system-structural analysis and forecasting; method of scientific generalization.

IV. RESULTS

The reform of local self-government and decentralization of power involves overcoming many challenges, namely: the dependence of territories on the center; infrastructural and financial weakness of communities; degradation of rural areas; high level of community subsidies; low level of investment attractiveness of territories, etc. (Figure 1.).

In Ukraine, the decentralization process began in 2014 with the adoption of the Concept of Reform of Local Self-Government and Territorial Organization of Power in Ukraine (04/01/2014), the Laws of Ukraine "On Cooperation of Territorial Communities" (06/17/2014), "On Voluntary Association of Territorial Communities" (05/02.2015) and amendments to the Budget and Tax Codes - regarding financial decentralization [5-10; 11; 19].

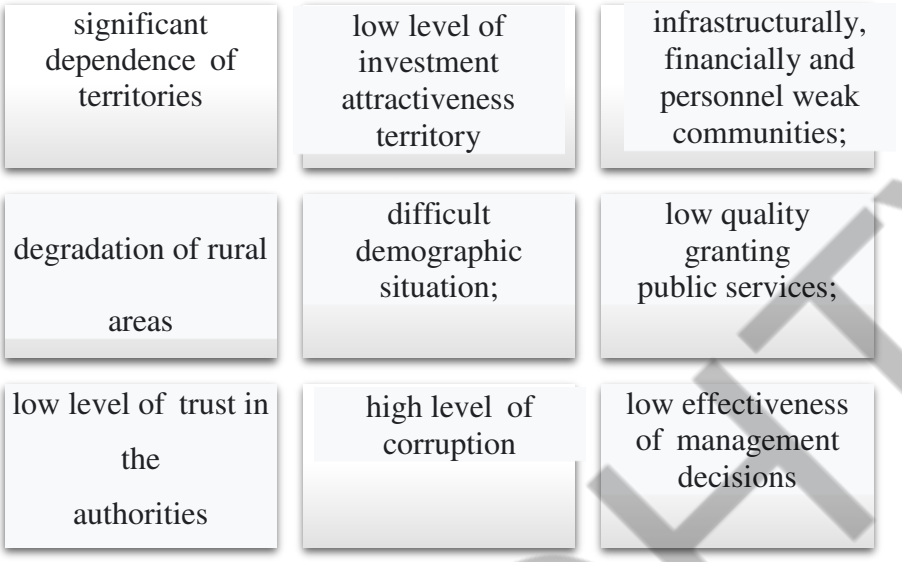

Fig 1. Consequences of the policy of total centralization of power in Ukraine
Source: systematized by the author

This process made it possible to form, in accordance with the provisions of the European Charter of Local Self-Government, a significant effective and capable institution of local self-government at the basic level – Territorial Communities (TC).

During the 6 years of the reform, 1,070 community centers were formed, in which 4,882 communities voluntarily joined. Of these, the first local elections were held in 936 TC. The government has approved long-term plans for the formation of the territories of communities in 24 oblasts, which cover 100% of the territory of the oblasts. The area of the formed TC is almost 47% of the total area of Ukraine. More than 70% of the population of Ukraine lives in TC and cities of regional significance. In accordance with the Law of Ukraine dated 04/16/2020 No. 562-IX "On Amendments to Certain Laws of Ukraine Regarding Determining the Territories and Administrative Centers of Territorial Communities", the Cabinet of Ministers of Ukraine determined the administrative centers and approved the territories of 1,470 capable territorial communities in which local elections in 2020 on a new territorial basis [12].

Thanks to the introduction of inter-municipal cooperation, communities got the opportunity to consolidate efforts and implement joint projects.

In particular, 1,354 territorial communities concluded 604 agreements on cooperation [13].

During the implementation of the reform, local self-government and territorial organization of power, approaches to strategizing regional development at the national, regional and local levels have undergone changes.

As a result of the decentralization reform, the independence of communities in the spheres of managing their own development, making strategic and tactical decisions, and managing the local budget was significantly expanded.

As of the beginning of the reform in 2014, only 6 regions in Ukraine were self-sufficient, which caused a significant regional disparity, and, accordingly, the quality of life and services received by Ukrainians. These challenges demanded radical reforms in terms of state administration, local self-government and territorial organization of power in Ukraine [13].

The decentralization reform gave an impetus to the formation of an efficient and closest to the citizen institution of power - local self-government. Voluntary unification of territorial communities allowed the newly formed bodies of local self-government to get the appropriate powers and resources that cities of regional importance previously had.

The interests of citizens living in the territory of the united community are now represented by the elected chairman, the body of deputies and the executive bodies of the community council, which ensure the implementation of the powers granted by law in the interests of the community. In settlements that are part of the united community, the right of residents to local self-government and provision of services to citizens is ensured by their elected elders.

According to the Law of Ukraine "On the Voluntary Unification of Territorial Communities" [8], the increase and unification of communities was carried out through voluntary unification taking into account the opinion of citizens. Determination of potential resource opportunities is mandatory when planning the creation of communities communities for economic and social development and the ability to provide quality services to residents.

Effective local self-government and its provision of progressive socio-economic development of the respective territories must be accompanied by an increase in the resource and financial base. Decentralized powers must be provided with appropriate resources for quality implementation. Therefore, with the introduction of changes to the Tax and Budget Codes, from January 1, 2015, local self-governments received more finances to increase economic capacity.

The united communities have acquired the powers and resources that cities of regional importance have, in particular, the inclusion of 60% of the personal income tax on their own authority in the local budgets of the TC. In addition, revenues from taxes remain entirely local: the single one, on the profit of enterprises and financial institutions of communal property and tax on property (real estate, land, transport).

In addition, TC have direct inter-budgetary relations with the state budget (before the reform, only regional and district budgets, the budgets of cities of regional importance had direct relations), to fulfill the powers delegated by the state, they are provided with appropriate transfers (subsidies, educational and medical subventions, development subventions community infrastructure, etc.). Legislative changes also gave local self-government bodies the right to approve local budgets regardless of the date of adoption of the State Budget Law.

After making changes to tax and budget legislation, the main taxes that fill local budgets (cities of regional importance, districts, united territorial communities).

Such improvements have already produced the first noticeable results. Own revenues of local budgets increased by UAH 200 billion from 2014 to 2019. (from UAH 68.6 billion to UAH 267 billion). This is a real tool of influence on the achievement of results and responsibility for the trust of communities.

On the other hand, in administrative-territorial units that do not earn the necessary amount for expenses, the basic subsidy is only 80% of the required amount (provided that the tax capacity index is less than 0.9).

Decentralization is the transfer of powers and finances from the state government to local self-government bodies. Decentralization of the power and financial powers of the state in favor of local self-government is one of the most defining reforms since Ukrainian independence.

The goal of the reform is the formation of effective local self-government and territorial organization of power for the creation and maintenance of a full-fledged living environment for citizens, the provision of high-quality and accessible public services, the establishment of institutions of direct people's power, coordination of the interests of the state and territorial communities [16].

Goals of local self-government reform and decentralization of power:

1. a system of administrative and territorial organization optimal for Ukraine has been formed;

2. capable local self-government capable of exercising its own and delegated powers;

3. communities participate in solving issues of local importance;

4. funding of regional policy ensures the development and increases the competitiveness of communities and regions;

5. the state monitors the legality of the activities of local self-government bodies.

Decentralization is the creation of conditions for the formation of an effective, responsible local government capable of providing a comfortable and safe environment for people to live throughout Ukraine, regardless of their place of residence.

Decentralization is the transfer of powers and budget revenues from state bodies to local self-government bodies. The goal of local self-government reform is, first of all, to ensure its ability to independently, at the expense of its own resources, solve issues of local importance. It is about providing territorial communities with greater resources and mobilizing their internal reserves [15].

Decentralization [4]:

- administrative - communities provide quality services: education, health care, social protection, land issues, housing and communal services, security issues, etc. It is important to convey to all residents that after the completion of the decentralization reform, the quality of services will depend only on them.

- financial - effective local self-government and its provision of progressive socio-economic development of the respective territories must be accompanied by an increase in the resource and financial base.

Principles of financial decentralization of power:

– efficiency and transparency: effective and transparent financial activity of state authorities, local and regional self-government, which excludes duplication of

functions, implementation of inefficient actions, swelling of the bureaucratic apparatus;

– responsibility: the responsibility of local and regional self-government bodies for the performance of their own competence in providing public goods must be full and exclusive;

– legality: the maximum transfer of rights, functions and responsibilities regarding financial activities to local and regional self-government under the conditions of preserving the unity of the state;

– involvement: maximum involvement of the population in the decision-making of local and regional affairs;

– priorities: the priority of the development of the public self-regulating financial mechanism over the bureaucratic state financial mechanism;

– provision: provision of the standard of living guaranteed by the Constitution of Ukraine in all regions of the state [16];

– compliance: achieving compliance in the scope of the transferred powers to carry out expenditures and mobilize the necessary financial resources for their financing at the level of power that covers the area of public good availability for consumers.

The development of territorial communities in the conditions of local self-government reform and decentralization of power in Ukraine is closely related to the improvement of the organization of life and activities of the population, the achievement of sustainable development of the territory. The economic and political prerequisites for the introduction of decentralization in Ukraine were created after gaining independence in 1991. The decentralization reform has made significant progress since 2015. Its irreversibility should be defined by the introduction of changes to the Constitution, the completion of the reform of the administrative-territorial system, and the legislative provision of financing the powers of territorial communities [16].

The main tasks for territorial communities in the process of managing the sustainable development of the region:

– social component – social basis and spatial expediency;

– economic component – achievement of anticipatory rates of economic development;

– ecological component - preservation of a favorable ecological environment;

– political component - an effective community management system.

Decentralization reform in Ukraine is designed to create capable united territorial communities, so the question of their resource potential is important.

After the decentralization reform, the united territorial communities received additional financial resources (Table 1).

Table 1. Income of the budgets of the territorial communities before the reform and after decentralization

Financial resources	Before the reform	After the reform
Personal income tax	–	60%
Excise tax on excise goods manufactured in Ukraine	–	13,44 % excise tax (fuel)
Excise tax on goods imported into the customs territory of Ukraine of excise goods of fuel	–	13,44 % excise tax (fuel)
Income from losses of agricultural and forestry production	–	75 %
Educational subsidy	–	according to the formula
Medical subvention	–	according to the formula
Subsidy for the formation of the OTG infrastructure	–	according to the formula
Subsidy for socio-economic development	–	according to the formula
DFRR funds	–	according to the formula

Source: systematized by the author [11; 18]

The decentralization reform gives united communities additional sources of financial resources that can be used to improve welfare, repairs, and develop education and culture in the community.

Financial support of territorial communities is the basis of their development, however, in order to increase their capacity, the issue of transferring the most important resource - land - to communities arose.

On January 31, 2018, the Cabinet of Ministers of Ukraine adopted the Order "On the transfer of state-owned agricultural land plots to communal ownership of united territorial communities." These are the legislative mechanisms for the transfer of land into the ownership of TC, including land outside the boundaries of settlements [19].

The order regarding the transfer of state-owned land outside settlements to communal ownership of the TCwas adopted on the basis of three normative legal acts:

– Land Code of Ukraine: Article 117 "Transfer of state-owned land plots into communal ownership or communally owned land plots into state ownership" [20];

– Decree of the Cabinet of Ministers of Ukraine "On the transfer of state-owned agricultural land plots into communal ownership of united territorial communities" [21];

– Law of Ukraine "On Local Self-Government": Article 26 [22]. Transfer of lands outside settlements to the disposal of communities -

it is primarily the strengthening of their capacity and a prerequisite for sustainable local development.

For territorial communities, after they acquire land outside the settlements, the resource base that local authorities will be able to dispose of for the benefit of citizens is significantly expanded.

In individual communities, land is the main source of filling budgets, they will be able to independently make decisions about the use of land resources to fill their own budgets.

For territorial communities, the transfer of state-owned agricultural land plots into communal ownership will have the following advantages:

- influence on the economic development of territorial communities due to the increase in land tax revenues;
- will enable territorial communities to control income from land lease fees outside the settlement and land tax from it;
- territorial communities will be able to develop general plans for the entire territory of the community and not only for individual settlements;
- will make it impossible for situations with land raiding to take place, which could happen until now.

Table 2. Transfer of state agricultural lands to the communal ownership of the territorial communities (TC) of the central regions of Ukraine in 2018-2020

Regions	2018 p.		2019 p.		2020 p.	
	The number of TC, which received communal ownership of rural land plots appointment	Land area, thousand hectares	The number of TC, which received communal ownership of rural land plots appointment	Land area, thousand hectares	The number of TC, which received communal ownership of rural land plots appointment	Land area, thousand hectares
Vinnytsia	34	37,8	2	0,7	62	168,7
Kyivska	9	8,1	7	9,4	5	29,1
Kirovohradsk	13	25,9	7	19,0	45	138,5
Cherkassy	26	40,5	28	32,9	61	117,9
All over Ukraine	**648**	**1469,99**	**139**	**62,0**	**1251**	**2002,4**

Source: systematized by the author basedon [23]

Land decentralization is an important reform in terms of decentralization, since land is a resource that can be used by territorial communities to increase budget revenues.

The transfer of land was carried out in compliance with the Decree of the President of Ukraine dated October 15, 2020 No. 449/2020 "On some measures to accelerate reforms in the field of land relations" within the framework of the implementation of land reform in the area of land decentralization [25]. Thus, in 2020, 2,002.4 thousand hectares of state agricultural lands were transferred to the communal ownership of 1,251 territorial communities of the central regions of Ukraine (Table 2.).

The unification of territorial communities provides for the transfer of property of territorial communities. Thus, in the case of unification of village, settlement, city councils into one territorial community, all property jointly owned by village, settlement city councils is the communal property of the united territorial community, and the rights and obligations related to such property belong to the united territorial

community. Commonly owned objects are called property, and in other words, they are institutions and institutions. But in the context of the decentralization reform and the property to be transferred, it is about real estate. It can also be integral property complexes.

Effective management of communal property: strengthens the capacity of territorial communities; directs the work of local self-government bodies to sustainable and balanced development; contributes to increasing investment attractiveness, development of high-quality public services and business in the respective territories.

Decentralization in the field of education is primarily the transfer of general secondary education institutions to territorial communities. If earlier in the field of education, the responsibility of communities was only for the effective functioning of preschool education institutions, then under the conditions of decentralization, responsibility is assumed for general secondary education institutions that were in their communal ownership [4].

In the central regions of Ukraine, the following decentralization changes took place in the field of education (Table 3):

– in the Vinnytsia region: 147 general educational institutions out of 46 TC, 36 TC were transferred to communal ownership;

– in the Kyiv region: 108 general educational institutions out of 24 TC, 16 TC were transferred to communal ownership;

– in the Kirovohrad Region: 49 general educational institutions out of 27 TC, 16 TC were transferred to communal ownership;

in the Cherkasy region: 174 general educational institutions out of 57 TC, 53 TC were transferred to communal ownership.

Decentralization in the field of health care - the transfer of paramedic-midwifery points, paramedic points, dispensaries, hospitals to the ownership of communities and effective provision of services [4].

The methodology for evaluating territorial communities is necessary for analyzing the capacity of communities, increasing the financial potential of territories and equalizing interregional financial disparities as much as possible.

Table 3. General educational institutions transferred to TC
(as of September 10, 2020)

Regions	**Number of TC**	**The number of general educational institutions that have been taken into communal ownership institutions**	**The number of general educational institutions that have been converted into communal ones property of TC**	**The number of TC that transferred the educational subvention to the district budget**
Vinnytsia	**46**	**36**	**147**	**5**
Volynsk	54	49	509	3
Dnipropetrovsk	71	34	130	4 4
Donetsk	13	12	89	1
Zhytomyr	56	54	412	–
Zakarpattia	17	7	60	9

Zaporizhzhia	56	43	368	1
Ivano-Frankivsk	39	39	242	1
Kyivska	**24**	**16**	**108**	**5**
Kirovohradsk	**27**	**19**	**49**	**1**
Luhansk	18	12	60	5
Lviv	41	35	210	–
Mykolayivska	42	29	121	1
Odesa	37	19	110	10
Poltava	53	44	183	3
Rivne	45	34	137	11
Sumy	38	37	215	–
Ternopilsk	54	39	236	1
Kharkivska	23	12	47	1
Khersonsk	33	29	114	2
Khmelnytska	52	46	338	1
Cherkassy	**57**	**53**	**174**	**4**
Chernivtsi	37	30	163	4
Chernihivska	50	43	269	1

Source: systematized by the author based on [24]

The given financial indicators are:

– is static information that reflects the state of affairs on the relevant date;

– reflect the individual most significant areas of financial and budgetary activity of communities;

- provide an opportunity to carry out a comparative analysis of identical parameters across different communities within individual regions.

For a comprehensive objective assessment, it is necessary to carry out a deeper analysis of the financial indicators of specific communities, to identify cause-and-effect relationships between the level of development of social and industrial infrastructure, the entrepreneurial and resource potential of the territory, demographic factors, etc. The intangible assets of the community should also be taken into account. The existing methodology for assessing the capacity of communities does not take into account the provision of real needs of territorial communities with available financial resources. Therefore, there is a need to supplement the assessment of financial capacity with indicators that will be able to reveal and evaluate in more detail the development of each TC region.

V. CONCLUSIONS

Territorial communities, in addition to the growth of their own financial capabilities, as a result of decentralization have other tools for ensuring economic development - external borrowing, independent selection of institutions for servicing local budget funds in relation to development and own revenues of budgetary institutions. Powers in the field of architectural and construction control and improvement of urban planning legislation have been decentralized, local self-

government bodies have been given the right to independently determine urban planning policy.

After the adoption of a series of laws on the decentralization of powers and regulation of land relations, communities will get the right to dispose of lands outside the settlements. The Verkhovna Rada of Ukraine adopted laws that provide an opportunity to decentralize part of the powers of the Central Committee of Ukraine regarding the provision of basic administrative services: registration of real estate, business, residence of a person - transferring them to the level of communities.

Draft laws designed to clearly demarcate powers in the field of education, health care, leisure, socio-economic development, infrastructure between local self-government bodies and executive power bodies at each of the territorial levels of the administrative-territorial system of the state.

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PROSPECTS FOR THE DEVELOPMENT OF CONTACTLESS PAYMENT IN THE CONDITIONS OF DIGITALIZATION OF THE BANKING SYSTEM

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Abstract. *Contactless payment technologies play an important role in the process of the system of bank settlements in the whole world, and in particular in Ukraine. At the same time, there is a problem of public refusal to cash in favor of contactless payments. The purpose of the article is to study the role and place of contactless methods of calculation in the economy of Ukraine and the world in terms of novelty and profitability, as well as to determine trends of their application.*

In the work, the tendencies of the introduction of contactless payments into the world banking system, and directly Ukrainian are analyzed. Strong, and weak sides, opportunities, and threats to the development of such technologies in the modern economy are identified. A survey was conducted among Ukrainian society on their attitude to contactless payments and identified the main obstacles to the dissemination of these technologies in Ukraine. Ways of solving the problem of digitalization of the banking system of Ukraine were proposed.

Keywords: *NFS technology, contactless payment, tokenization, face recognition payment, mobile payment, and QR-code payment.*

I. INTRODUCTION

Payments using bank cards, smart applications, and direct contactless payments are of great importance in the accumulation of funds in banking systems, which give users new profit opportunities and increase the transparency and reliability of the financial system in general.

The systems of contactless payments are now actively developing, and their use has a very significant perspective in the whole world and Ukraine in particular. The tendency of increasing the number of bank cards with the built-in NFC chip, as well as the growth of the size of POS terminals, gave Ukraine bonus advantages over the countries of Eastern Europe, which enabled it to quickly introduce Google pay and Apple pay systems into the Ukrainian financial sector. The leading trend in the development of the modern economy of developed countries is the development and perception by users of the newest instruments of financial calculations. Of course, contactless payments, which have become a substitute for old cash payments, are more effective and more productive, and they also have a much greater degree of protection. Leading countries such as Sweden, the United States, Japan, and China, are reducing the amount of cash flow in the everyday life of the population. They actively stimulate the development of the infrastructure of contactless cards, the use of Internet-wallet, and Internet payment.

With the start of COVID-19, the process of payment systems' digitalization became one of the main missions of society. Global, concern about infection and the

role of the permits in spreading emphasized the need for contactless payments. Popularity began to acquire contactless payments, which exempt users from the congenic burden and minimize the term in processing transactions quite significantly. This growing ecosystem further offers a safe and convenient way to conduct cashless transactions. According to a global Mastercard survey conducted in April 2021, about 8 out of 10 consumers report that they are using contactless payments. From 46% to 52% of clients changed the standard bank card to the one offering contactless payment. Most consumers consider contactless payment as a clean and faster method of payment since it allows them to carry out transactions 10 times faster than other payment methods. This allows clients to make more quick and comfortable settlements in different types of institutions [1].

II. LITERATURE ANALYSIS

Given the relative novelty of this topic, we still have no significant theoretical basis for Ukrainian works, but we can select the research conducted by L. P Bondarenkom, N. B. Yaroshevichom, A. B. Tarabynovice, and others.

Studies of various aspects of contactless payment methods were covered in a considerable number of foreign works by scientists O. Gough, R. Boon, J. LIM, Z. Dubinsky, D. Clark, A. Jeffries, and A. Villarreal.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The main purpose of the work is to study the general tendencies of the introduction of contactless technologies in the economy as a stage of the banking system's digitalization and analyze the readiness of the Ukrainian society to transition to contactless methods of payment, to identify the main obstacles to this process and their solution.

The tasks of the work are:

- analysis of the international situation in the sphere of the use of contactless payment methods, investigation of the trend of their development, and identification of the main advantages of the use of contactless payment methods.

- measuring consumer benefits in the sphere of payment and determining the main obstacles to the integration of the latest payment technologies into the Ukrainian economy.

The object of scientific work is non-contact payment under the conditions of the digitalization of the banking system of the world and Ukraine.

The subject of scientific work is the assessment of the effectiveness of the non-contact payment system implementation in Ukraine and the determination of its interference.

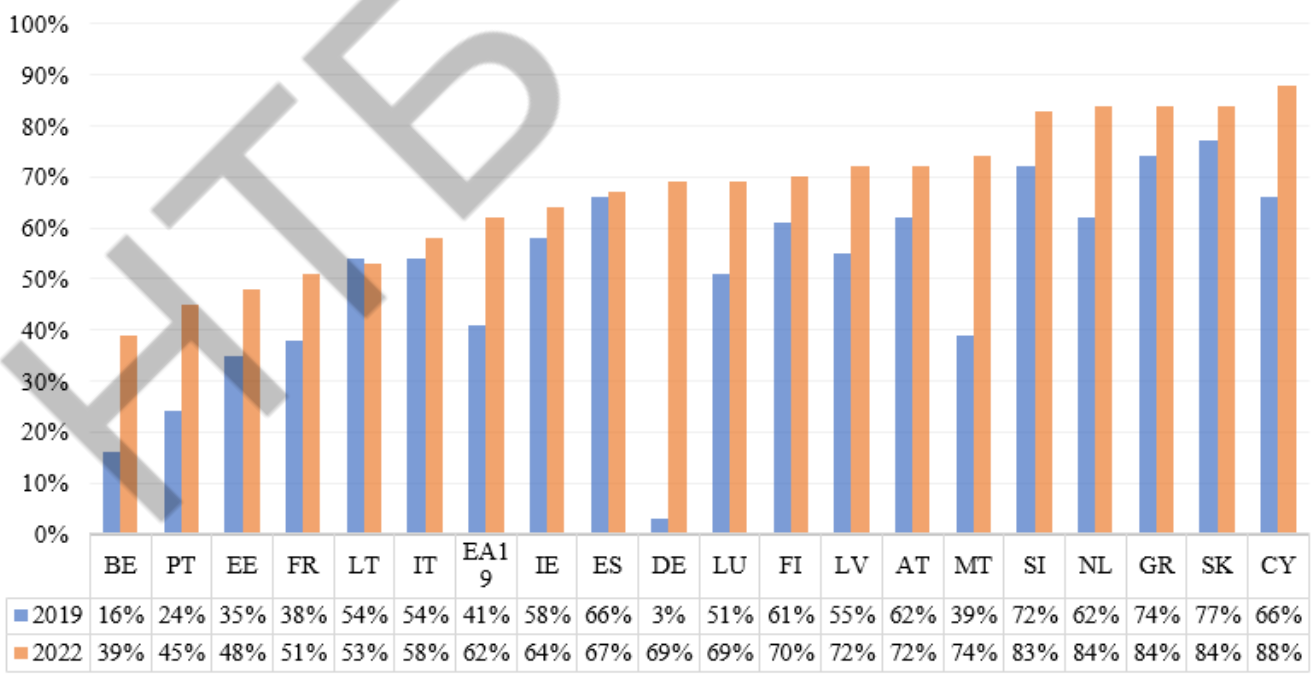
The following methods were used during the study:

The survey, analysis and synthesis, graphic methods, method of scientific abstraction, method of systematization, as well as of inducement and deduction.

IV. RESULTS

4.1 Trends in the development of the system of contactless payments as a stage of the banking system's digitization. Analysis of prospects and disadvantages of their use.

The concept of contactless payment refers to the possibility of payment using a card or electronic device, holding it near the payment terminal of the seller. In 2022 these two benefits were considered one of the most advantageous factors of card payments. When making a payment with a contactless card, checking the card information with a chip and a PIN code is important before the transaction. The highest transaction cost limit was increased to a legal level of €50 per transaction in all euro-zone countries in 2019. A PIN can also be required after a certain number of transactions per day or when the total amount has been reached, making contactless payments more reliable against fraud. Contactless card payments in POS increased from 41% of all card payments in 2019 to 62% in 2022 [2]. The change of habits is significantly different between different countries of the euro area. Lithuania was the only country where contactless payments as a share of the total number of card transactions decreased from 54% to 53%; however, this should be treated with caution because of possible margin errors. Cyprus was a country where contactless payments had the highest share of total card payments in 2022 (88%), followed by Slovakia (84%) and Greece (84%). Belgium was the country with the lowest share of contactless card payments in 2022 (39%), as it was in 2019 [2]. Germany in particular saw a significant increase in contactless payments as a share of total card payments, although it should be noted that the first point of data for Germany is from 2017, not from 2019 (Fig. 1).



	BE	PT	EE	FR	LT	IT	EA19	IE	ES	DE	LU	FI	LV	AT	MT	SI	NL	GR	SK	CY
2019	16%	24%	35%	38%	54%	54%	41%	58%	66%	3%	51%	61%	55%	62%	39%	72%	62%	74%	77%	66%
2022	39%	45%	48%	51%	53%	58%	62%	64%	67%	69%	69%	70%	72%	72%	74%	83%	84%	84%	84%	88%

Fig. 1. Share of contactless payments in all card payments at the POS in terms of number and value of transactions, by country in the period of 2019-2022

Sources: Based on [3]

When it comes to the cost of non-contact payments operations compared to the total cost of card transactions, the share of contactless payments increased from 27% to 50%. Greece and Finland were the only countries that saw a share in the value of non-contact agreements, down from 75% to 69% and 36% to 35%, respectively. Three countries with the highest percentage of contactless card payments in 2022 were Cyprus (81%), Slovakia (75%), and Slovenia (74%); Belgium has the lowest index (28%) [2].

In 2020, digital payments in general tended to grow rapidly. According to Capgemini's World Payment Report [4], digital payments grew by 53% (Fig.2).

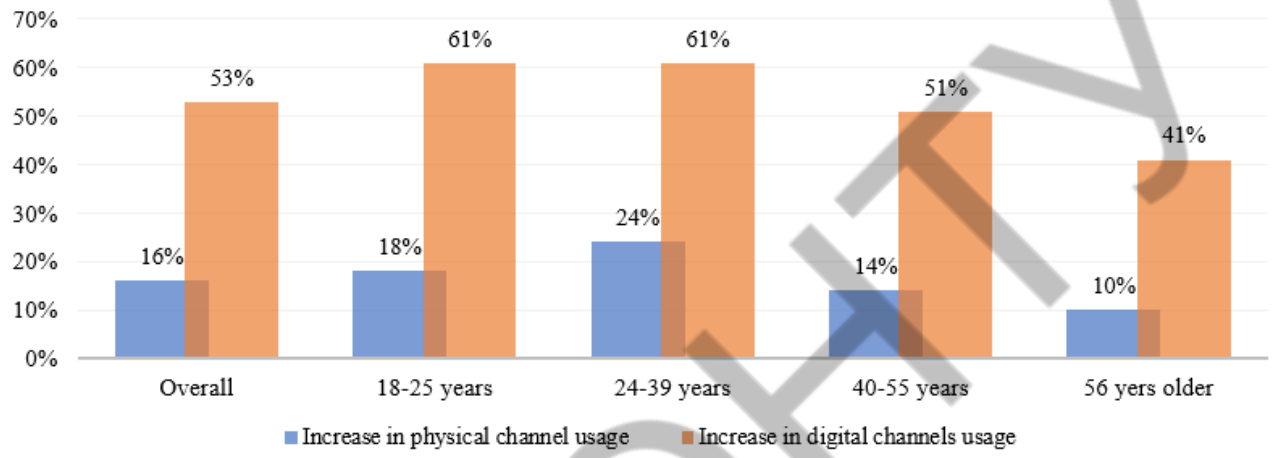


Fig. 2. The level of adapting digital payment compared to physical payment in 2020

Source: Based on [4]

It is worth noting that clients also experimented with new forms of payments, including:

41% tried contactless cards.

35% added the card to the digital wallet.

27% of clients experimented with QR code payments [5].

From all regions, APAC had the highest volume of global non-cash transactions, reaching 243.6 billion transactions in 2019 - a growth rate of 24.7% in just one year. In the EU, non-cash transactions increased by 12% from 2018 to 2019 (Fig. 3).

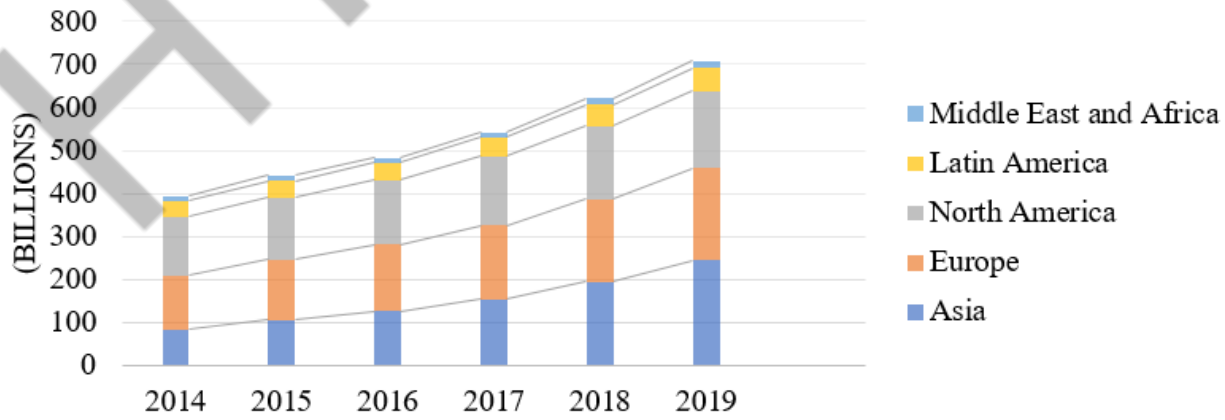


Fig. 3. Non-cash transactions around the world in the period of 2014-2019 (billions)

Source: Based on [1].

It is worth noting that credit and debit card payments are still dominant in eCommerce payments, and mobile payments are expected to reach the fourth [5].

Advantages for consumers:

- Fast, convenient, and safe payment for low-cost purchases – perception of safety and convenience stimulated the preference for contactless cards. Around the world, almost half of the respondents (46%) have changed their standard bank card to one offering contactless payments – this share is growing up to 52% among those under 35.

- No effort is needed, or a PIN code is ideal for customers who save time. The global pandemic has led to increased consumer concern about cash use and the benefits of non-cash payment. Most respondents (82%) say contactless payments are a more hygienic and safe way of payment, and contactless payments are 10 times faster than others, which allows clients to save time when paying in the appropriate institutions.

- Convenience for public transport, motor transport, parking facilities, petrol stations, and pharmacies. There is no need to wait in long queues for purchasing a metro ticket, leave the car to get a ticket for its parking, and so on, just to put a non-contact payment and the operation is completed.

- Use of mobile wallet for transactions. You do not need to stand in line for everyday purchases – fast service when buying food and drinks, entrance tickets for entertainment establishments, and shopping in shops [6].

Benefits for enterprises and businesses:

- Faster transactions effectively move customers through the payment process – generating the potential to increase sales.

- Modernized payment processes reduce operating costs and increase efficiency.

- Increased customer expenses, increased frequency of purchases, increased loyalty – contactless payment function encourages consumers to frequently use debit cards. Once consumers have access to contactless technology, the frequency of transactions with debit card points of sale is increased by 7% per year [7].

However, there are a significant number of vulnerable places of the contactless payment system, the following risks and ways of their solution [8].

Table 1. RF Vulnerabilities: Attack Patterns, Risks, and Countermeasures

Vulnerability	Attack	Attack Set-up	Risks	Countermeasures
A legitimate contactless payment transaction can be captured using a clandestine antenna	Passive Eavesdropping	Spy-reader near-read data exchanges	Leakage of card account data Leakage to manufacture a fake card or a clone	Encryption of data exchange Authenticate contactless card

Contactless card responds when it detects a 13.54 MHz frequency	Clandestine scanning/ Electronic Pick Pocket/ Skimming Replay Attack	Clandestine reader in proximity with the contactless card Skimming for replay attack (using predetermined challenge)	Retrieval of data for cloning Initiation of the fraudulent payment order	Reader authentication Online authorization Quality Random Number
POS is confused if it has authenticated remote chip instead of presented	Grandmaster Chess/ Replay/Man-in-the-middle Attack	Fake Card for carrying MITM attack Using skimmed original cards	Unauthorized Payment	Binding transaction time foils replay attacks as it takes extra time
Weak Crypto implementation due to limited processing power & battery	Brute Force Attack	Brute Force Tools to read data	Eavesdropping transactions for card cloning	Lightweight crypto is standardized. It takes care of this attack
Activating all cards in proximity leading collision	Denial of Service Attack	Activating multiple cards	Disruption in transaction processing	Standardization like ISO 14443 solves collision problem

Source: Based on [9]

4.2 Definition of prospects and obstacles to the introduction of contactless payment method in the Ukrainian banking system

In recent years, Ukraine has experienced a real payment revolution. We have long been accustomed to using a bank card anywhere and without any additional fees – and at the same time to receive cash and other bonuses for purchases. BA more, do not necessarily even have a physical card. You can pay for the purchase by phone, any gadget, and even your face. According to the results of May 2022, the total number of issued payment cards in Ukraine reached 103,6 million units. This is 13% more compared to the pre-war January 2022.

At the same time, in May 2022, compared to January of this year, the number of payment cards with which the expenditures were carried out every month was reduced. Their number decreased by 11% – out of 48,2 million units. in January up to 42,8 million pieces. in May [8].

Despite the decrease in the total number of contactless and token payment cards (by 6% and 15% respectively), their popularity among Ukrainians is very high. The total share of contactless and token payment cards among all active cards is 60% (this year in January – 58%) [8].

In general, today the token is approximately every sixth active payment card (at the beginning of January – approximately every seventh); the contactless payment card is about every second (as at the beginning of January).

As a result, less than a fifth of transactions (18,2% in amount and 16% in quantity) were carried out in the trade network with a physical reading of data from the

card carrier. Other transactions were contactless (with a contactless card or with smartphones and other gadgets). Their amount this year in May amounted to UAH 79,2 billion [10].

We surveyed the prevalence of the contactless payment method and the main problems of its implementation. The research was conducted among students of Ukrainian universities since this group of the population is considered the most progressive in the field of technology and is open to new. In total, more than 150 respondents took part in the survey. We have studied their payment habits and attitude toward various payment instruments and financial services. We want to share the results and our conclusions.

Taking into account the results of the Payment Method Survey (Fig. 4), it is possible to conclude that the majority of respondents prefer a contactless payment method, and only 7% use cash or contact cards (12%)

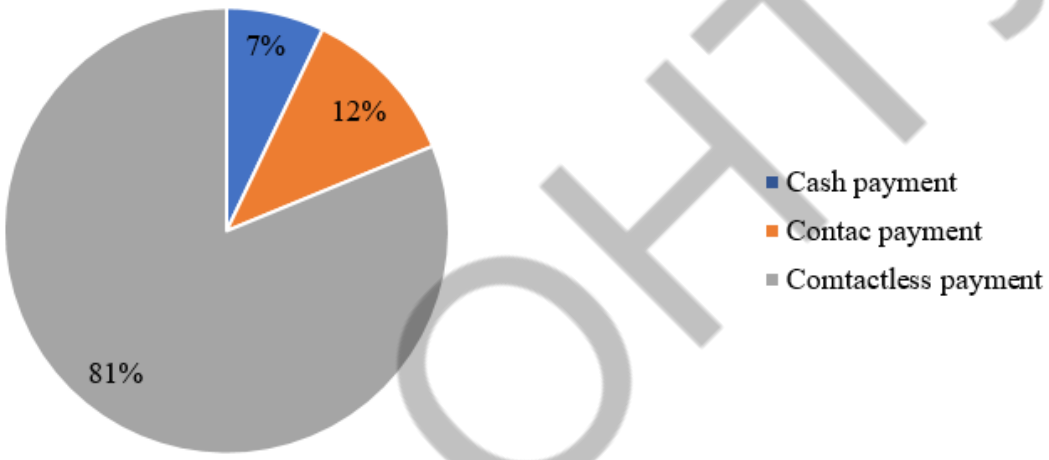


Fig. 4. The results of the survey "What payment method do you prefer?"
Source: Based on the research conducted by the authors.

According to the results of the survey on the change of payment methods with the onset of the pandemic (Fig. 5), it is possible to emphasize that almost half of the respondents changed their payment habits exactly under the influence of COVID-19.

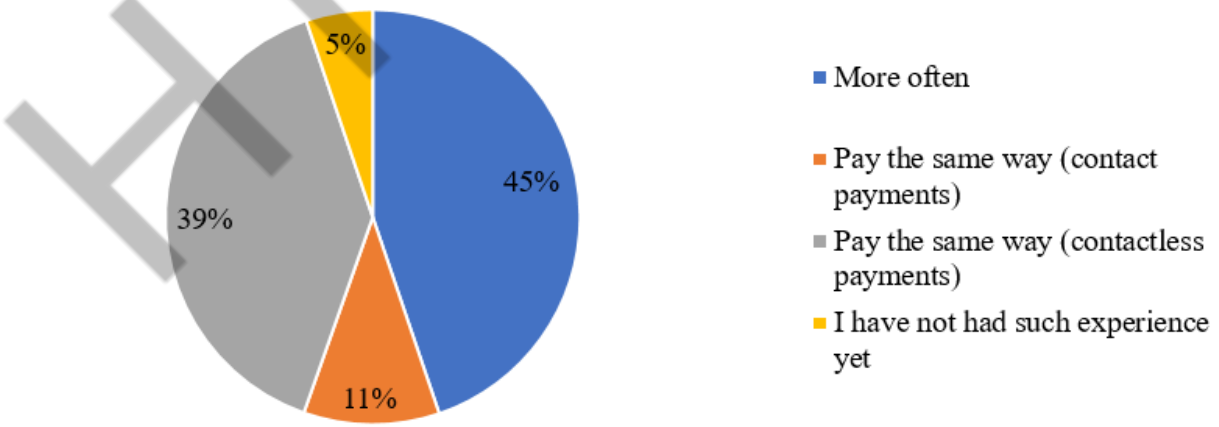


Fig. 5. Results of the survey on increasing the use of contactless payment methods with the onset of the COVID-19 pandemic.
Source: Based on the research conducted by the authors.

According to the results of the survey "How often you have faced the situation of lack of devices for maintenance of contactless?" (Fig. 6), one can conclude that one of the main obstacles to the transition to contactless payment methods is the absence of appropriate devices for their maintenance.

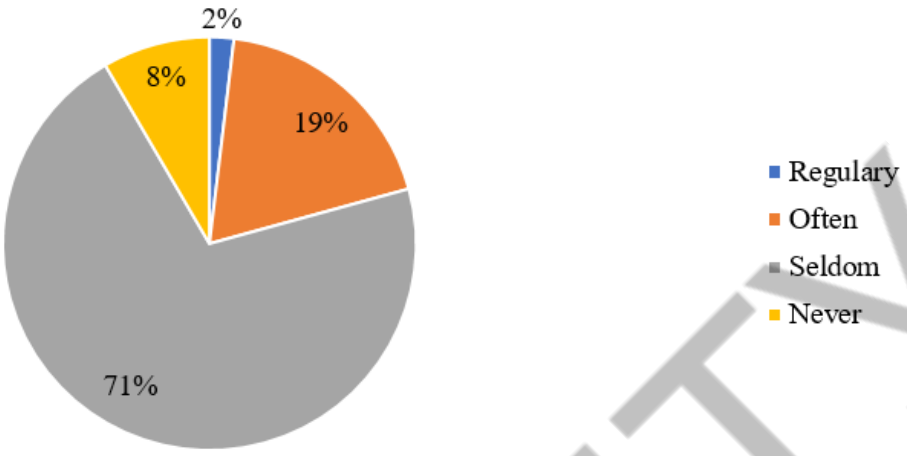


Fig. 6. Results of the survey "How often you have faced the situation of lack of devices for maintenance of contactless?".
Source: Based on the research conducted by the authors.

The banking system has not reached the stage of devitalization, but still cash plays an important place in the economy of Ukraine (Fig. 7). Still not everywhere can afford a cashless payment method, and as a result, clients are not ready to give up the cash.

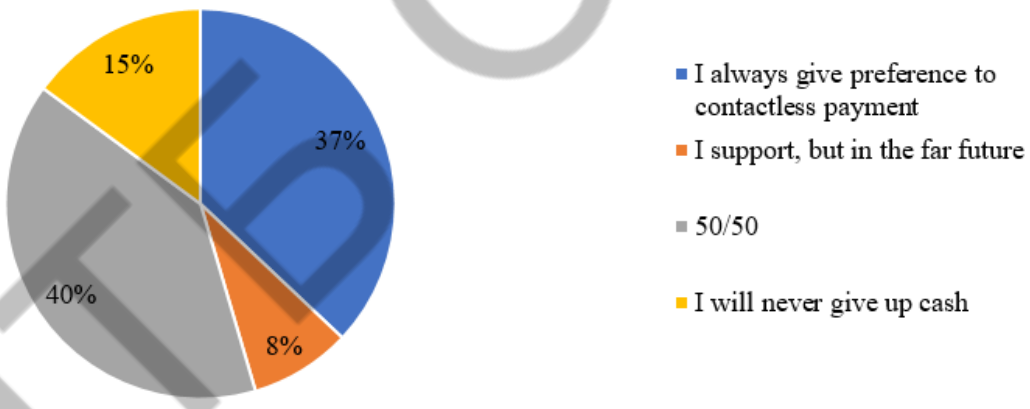


Fig. 7. The results of the survey "How do you feel about the refusal of cash in favor of contactless payment?".
Source: Based on the research conducted by the authors.

The survey results show that 34% of respondents are ready to replace their bank cards with contactless cards, while 56% have already done so (Fig. 8).

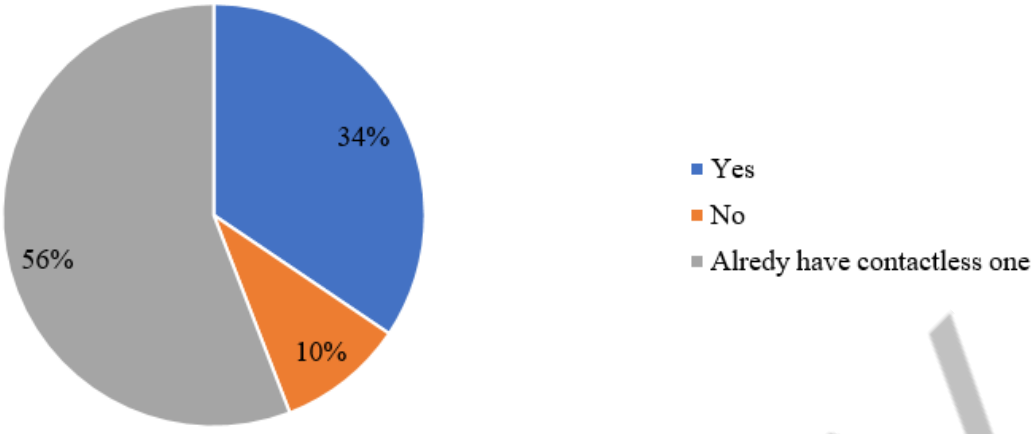


Fig. 8. Results of the survey "Are you ready to replace your top-of-wallet card with a contactless one?".
Source: Based on the research conducted by the authors.

According to the survey on 20.01.2023 (Fig. 9), the arrival in Ukraine of Apple pay and Google pay has become a catalyst for the increasingly active use of smartphones as a universal payment instrument, which allows simultaneously to "bind" several payment cards and choose for a specific payment the most suitable, taking into account loyalty programs, cash-runs or promotional offers.

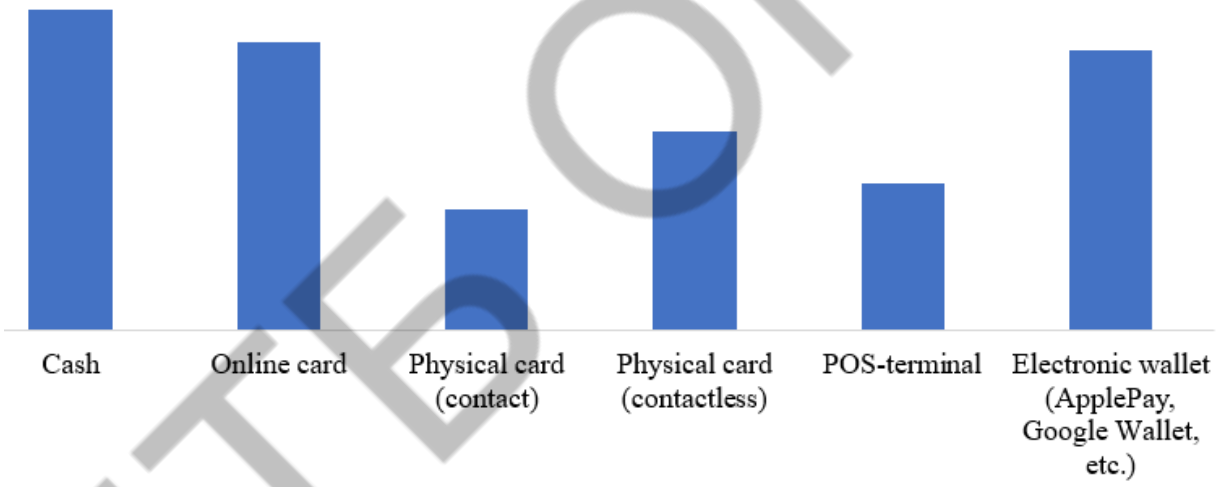


Fig. 9. Statistics of the most used payment methods during the last month.
Source: Based on the research conducted by the authors.

As previously mentioned, the main advantages of the contactless payment method are speed, convenience, and safety. In our research (Fig. 10) 96,6% of respondents emphasized convenience and 89,1% time savings.

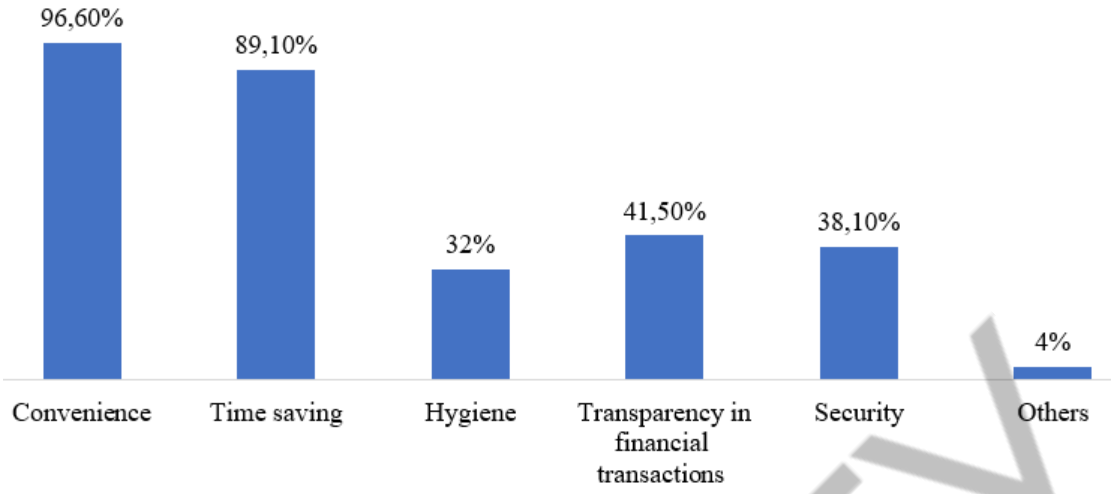


Fig. 10. Results of the survey on the advantages of using contactless payment methods.
Source: Based on the research conducted by the authors.

Taking into account the results of a survey on the main obstacles to the use of contactless payment methods (Fig. 11.), one can conclude that one of the main obstacles to the application of contactless payment methods is the absence of payment terminals with the possibility of contactless payment.

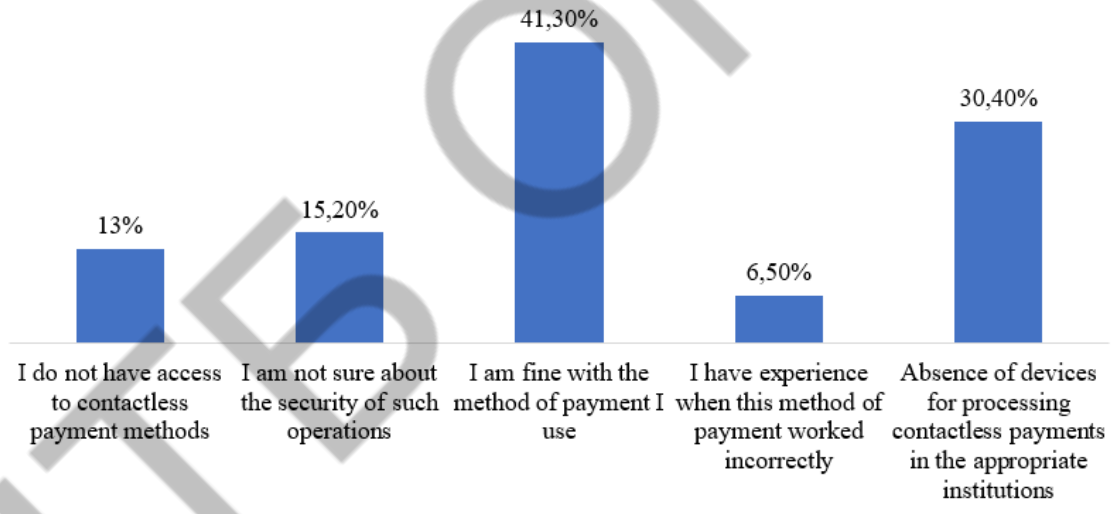


Fig. 11. Results of the survey on the main obstacles to the use of contactless payment methods
Source: Based on the research conducted by the authors.

Thus, analyzing the general situation of integration of contactless payments into the Ukrainian economy, we can say that in 2022 digital payments received special value. Contactless payment became a timely and convenient alternative during the COVID-19 pandemic when cash usage could threaten health. That is why it is not surprising that this year Ukrainians started to use cashless payment by 18% more often, namely contactless payments increased by 51%.

With the help of online payments, Ukrainians became closer to international commercial sites: Amazon, eBay, and AliExpress. If before making purchases on the world markets could only large businesses, now it is possible to buy goods not only in retail but also in wholesale (big order) can any user of the Internet. For example, many

start-up businessmen are bought at AliExpress, and then sell goods in retail through their private points or Internet sites.

Thus, new payment technologies improve life in Ukraine for both simple buyers and businesses. This opens up new investment and development opportunities for the country as a whole and every citizen in particular.

V. CONCLUSIONS

Having conducted this research we have received the following result:

The work of modern scientists played a significant role in our research. In domestic and foreign works there is quite a clear idea about contactless payments. In particular, it is observed in the works of such scientists as L. P Bondarenko, N. B. Yaroshevich, A. B. Tarabinovich, O. Gough, R. Boon, J. LIM, Z. Dubinsky, D. Clark, A. Jeffries, A. Villarreal.

Summing up the analysis of the development of a non-contact payment method in the world, it is possible to note that this process is gaining momentum of rapid growth. The COVID-19 pandemic has had a significant impact on the choice of payment method, which has led users whom previously preferred contact payment methods to move to contactless.

If we talk about the situation in Ukraine, we can emphasize that our country has had significant success in the process of the settlement process. Thus, in 2019 it was included in the top ten largest supporters of contactless payments. The results of our research have shown that people are actively moving to the newest payment methods, arguing with the convenience, speed, and transparency of the process. The obstacle to the more active development of the contactless payment segment, as well as non-cash settlements in general, is still insufficient development of payment infrastructure: According to Mastercard, more than 60% of small and medium-sized businesses in Ukraine work exclusively with cash, simply not giving clients an alternative. It is also not a secret that some traders are only requesting to provide POS terminals with outlets de jure, and the terminal can be in the status of "not working", "repair" or "frozen" for weeks. The economy, which is alive due to the distortion of the volumes of real turnover and tax evasion – is the main opponent of the widespread introduction of non-cash payments.

In this way it is possible to form the main directions of the solution to the problem of digitalization of the banking system of Ukraine:

1. Ensuring the development of payment infrastructure - the network of acceptance of contactless payments should develop, as the market of Ukraine is not far oversaturated with payment terminals. Especially their lack is felt in small cities. Therefore, society should make every effort to provide the maximum possible number of institutions providing various types of services by payment terminals.

2. Not less important factor is an increase in financial literacy of the population to inform not only about the possibility of using contactless bank cards and NFC technologies but also about the advantages of contactless payments, in particular financial.

3. A rather effective way to solve the above problems is also the stimulation or encouragement of contactless settlements using the introduction of certain restrictions on cash settlements, the additional issue of token cards, and the introduction of new functional possibilities for contactless settlements with the use of cards or NFC technologies.

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HYDROPOWER INDUSTRY OF UKRAINE: CURRENT STATE, PROSPECTS AND FISCAL INSTRUMENTS TO STIMULATE ITS DEVELOPMENT

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Abstract. *The aim of this work is to determine the main features of the current state, problems and prospects for the development of hydropower in Ukraine, as well as to analyze the potential for using fiscal instruments to stimulate this industry. The structure, location, generated capacities of the largest HPPs and PSHs of Ukraine are characterized. The dynamics of hydropower consumption in Ukraine is presented. Political, economic, socio-cultural and technological factors of the external environment for the development of hydropower are identified. The role and risks of the hydropower industry in supporting the energy balance in the conditions of a full-scale invasion of the Russian Federation into Ukraine are determined. The necessity of post-war modernization of hydropower in the context of the principles of sustainable development is shown. The potential effectiveness of the use of fiscal instruments (environmental tax) to stimulate the post-war development of the hydropower industry is substantiated, taking into account the principles of environmental responsibility of industry.*

Keywords: *hydropower, hydropower potential, renewable energy sources, fiscal instruments, environmental tax, environmental taxation, full scale invasion, PEST analysis.*

I. INTRODUCTION

One of the modern directions of sustainable development of the world economy is an active transition to renewable energy sources. Such energy sources contribute to the maximum limitation of the impact of human activity on the environment. One of the branches of renewable energy is hydropower, which generates electricity from the kinetic energy of water movement. The active development of this branch of the energy system has long been the norm for modern developed countries. In Ukraine, powerful hydropower complexes have also been operating for a sufficient amount of time, however, a relatively small share of hydropower in the total electricity generation by the United Energy System of Ukraine, a weak level of development of the investment environment, current political and socio-economic challenges (full-scale invasion of the Russian Federation into Ukraine) actualize the need for a more detailed studying the current state and prospects for the development of hydropower in Ukraine. Fiscal instruments were chosen as the object of study of the instruments of post-war stimulation of the development of this industry due to their effectiveness and significance for the economy of modern developed countries.

II. LITERATURE ANALYSIS

The hydropower industry of Ukraine has been developing for quite a long time, therefore, researchers have already prepared a sufficient number of scientific papers on the problems of the state and prospects for the development of this area. Of course, the hydropower industry is constantly evolving, so it makes sense to analyze only newer scientific works and other sources of information.

Vlasyuk Yu. S. and Stefanyshyn D. V. conducted a number of studies, the subject of which were the problems and prospects for the development of small hydropower in Ukraine. Sukhodolya O. M., Sidorenko A. A., Behun S. V. and Bilukha A. A. analyzed the current state and main risks, key tasks for the development of the hydropower industry in Ukraine. Obodovskyi O. H., Danko K. Yu., Pochaievets O. O., Obodovskyi Yu. O. proposed a method for determining the hydropower potential of rivers. Petrakov Ya. V. and Hnedina K. V. developed a methodology for the integral assessment of the impact of alternative energy on the environment.

The issue of the impact of the full-scale invasion of the Russian Federation on the hydropower sector is completely new, because so far it is precisely investigative journalism that has been carried out most of all in this area. Interesting analytical materials were prepared by Butsko D., Konev V., Harasym A. and Kelm N.

Separately, it should also be noted scientific research on the problems of environmental taxation. This topic has also repeatedly become the subject of research by scientists from various countries. The impact on ecotaxes on carbon dioxide emissions was studied by Runst P., Höhle D. The evolution and development prospects of environmental taxation were studied by Barde J. P., Owens J. In Ukraine, environmental taxes were studied by Nikola S. O., Husiev A. O., Suchek S. I. and other scientists.

Despite a fairly wide base of scientific research on the problems of hydropower and environmental taxation, the problem of using environmental taxes as fiscal instruments to stimulate the hydropower industry remains insufficiently studied. And in the context of the prospective postwar modernization of the entire industrial complex of Ukraine, this topic is of particular relevance.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The aim of the study is to determine the main features of the current state, problems and prospects for the development of hydropower in Ukraine, as well as to analyze the potential for using fiscal instruments to stimulate this industry.

The object of the study is the current state and prospects for the development of the hydropower industry in Ukraine as a renewable energy sector.

The subject of the study is a general description of the current state, principles, conditions, prospects, threats, as well as fiscal instruments to stimulate the development of the hydropower industry in Ukraine.

Research methods: during this study, general scientific and special research methods were used, including: analysis and synthesis, abstraction, a systematic approach to the phenomena and processes under consideration, induction and deduction, concretization, analogy, comparison, grouping, PEST-analysis.

IV. RESULTS

4.1. Hydropower industry of Ukraine: current state, problems and development trends

Hydropower is "a branch of renewable energy, as well as a set of large natural and artificial subsystems that serve to convert the kinetic energy of water into electrical energy" [1]. This definition of hydropower, formulated by PJSC "Ukrhydroenergo", emphasizes a very important feature of the hydropower segment of the Ukrainian energy industry – its renewable nature. Compared to traditional energy sources based on the use of fossil fuels (gas, oil, coal, etc.), such energy sources pollute the environment much less and do not exploit very limited fossil resources. At the same time, there are factors that limit the pace of development of energy sectors based on the use of renewable energy sources: the dependence on climatic conditions of many areas of such energy (the presence of rivers, wind power, and so on), the need to invest significant funds in building and supporting the operation of appropriate energy complexes. Due to the above factors, at the moment, the share of hydroelectric power plants and pumped storage power plants in the total electric power industry of Ukraine is very limited – 6.7% as of 2021 [2].

Here are the general characteristics of the hydropower industry in Ukraine [3]:

- the basis of the functioning of the hydropower industry in Ukraine is the river system, represented by almost 63 thousand rivers with a total length of more than 200 thousand km, of which 113 have a length of more than 100 km, while the river flow of fresh water reaches 87.14 billion m^3;
- the hydropower sector of the Unified Energy System of Ukraine is represented by 10 high-capacity hydroelectric power plants (more than 10 MW), about 50 small-capacity hydroelectric power plants (less than 10 MW), 4 pumped storage power plants;
- the total capacity of generated hydropower reaches 5350 MW, while the share of high-capacity hydropower plants is 97.2%;
- the largest HPPs of the energy system: Dnipro HPP, Dniester HPP, Kremenchuk HPP, Kaniv HPP, Kyiv HPP, Kakhovka HPP, Seredniodniprovska HPP; the largest PSHs: Dniester PSH, Kaniv PSH, Tashlyk PSH.

Information about the largest HPPs in Ukraine and a map of their location are presented in Figure 1.

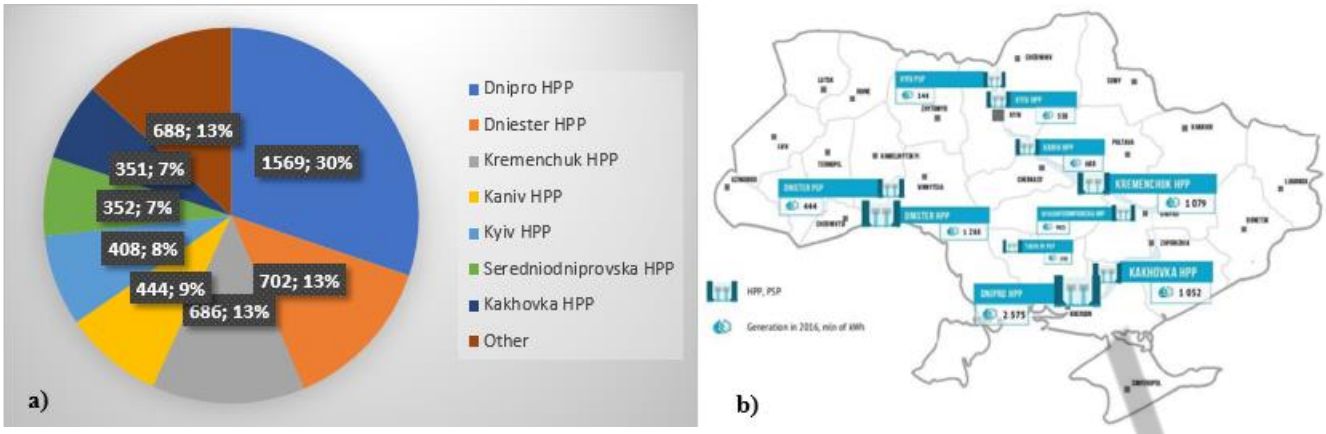

Fig. 1. Structure and location of the largest HPPs in Ukraine:
a – absolute and relative indicators of the capacity of hydropower produced by HPPs*, b – map of the location of the largest HPPs and PSHs in Ukraine**
*source: built by the author based on [4]
**source: [5]

The total consumption of hydropower in Ukraine is characterized by an unstable trend, depending on both external and internal factors. The largest drop in the indicator of hydropower consumption (by 2.56 times over the period 2013-2015) is associated with a crisis period for the economy – the annexation of the Crimean Peninsula and the outbreak of war in the East of Ukraine. The period 2015-2018, on the contrary, demonstrates a stable positive growth trend of the indicator – from 464 thousand toe to 897 thousand toe. The dynamics of hydropower consumption in Ukraine is shown in Figure 2.

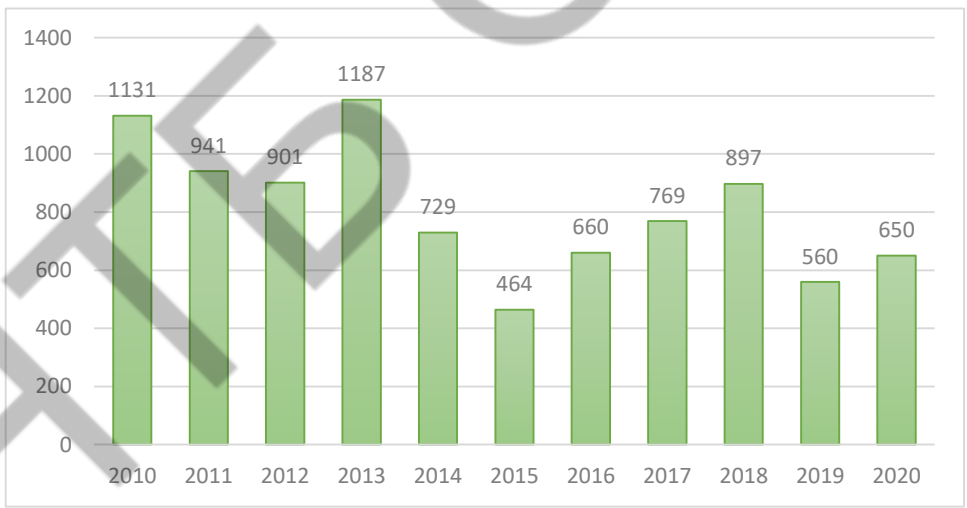

Fig. 2. Dynamics of hydropower consumption in Ukraine, thousand toe *
*source: built by the author based on [4]

The share of the total installed capacity of HPPs and PSHs in the energy complex of Ukraine (6.7% as of 2021) is significantly less than the share of hydropower in the entire world's electricity (16.8% as of 2020) [6]. This situation can be caused by independent unchanging factors (insufficiency of the country's water resources, typical, for example, for some states of the African continent) or a number of external and internal reasons related to the insufficient development of the industry (for example, limited funding for projects related to the hydropower complex). Both groups of factors

are characteristic of the Ukrainian hydropower industry. The provision of Ukraine's own water resources is quite low – only 1 thousand m^3 (this indicator is one of the lowest in Europe) [3]. But even the potential inherent in Ukraine is not fully used. To characterize the potential of water resources as a possible source of hydropower generation, the concept of hydropower potential is used. That part of the hydropower potential, the use of which is economically justified, is called the economic hydropower potential [7]. In Ukraine, the calculated economic hydropower potential reaches 17.5 billion kWh, and the actually used one is 11 billion kWh. Thus, the Ukrainian hydropower industry uses only 62.86% of the economic hydropower potential. This indicator is significantly lower than that of other developed countries: 95% in France, 85% in Switzerland, and 84% in Italy [3].

It should be noted that reaching the level of utilization of the entire economic hydropower potential is not justified from an environmental point of view. Here it is important to pay attention to the fact that although hydropower belongs to renewable energy sources, hydropower *is not* absolutely ecological kind of industry. The environmental damage from overexploitation of water resources is as follows [8]:

- destruction or damage to river ecosystems;
- flooding and erosion of surrounding soils;
- flooding of individual ecological biotopes;
- violation of the oxygen regime and hydrogen sulfide concentrations in rivers.

Accordingly, the concept of ecological hydropower potential is sometimes considered as an environmentally friendly part of the economic hydropower potential [9]. A country that follows the principles of sustainable development should limit the development of the hydropower industry precisely at the level of maximum use of the ecological hydropower potential. However, in Ukraine, the use of hydropower potential does not even reach the ecological level, as evidenced by the lagging behind the corresponding indicators of developed Western countries.

Thus, it can be confidently stated that the hydropower industry of Ukraine has the potential for development. However, the questions of principles, conditions and prospects for the development of the hydropower industry remain open. Let's consider them in more detail.

To analyze the conditions for the development of the hydropower industry in Ukraine, we will conduct a PEST analysis, its results will be presented in Table 1 [1, 3, 10].

Table 1. PEST analysis of the hydropower industry in Ukraine

P (Political)		**E (Economical)**	
Positive Factors	Negative factors	Positive Factors	Negative factors
1) Legal and regulatory support for the activities of the hydropower industry has been developed (Law "About the Electricity Market", Energy Strategy of Ukraine, Hydropower	1) The war situation in the country (targeted attacks by the enemy on the energy facilities of Ukraine, the capture of the Kakhovka hydroelectric power station, and so on)	1) Growing demand for renewable energy 2) Tax incentives for producers of alternative energy industries	1) Limited presence of foreign investors in the Ukrainian hydropower market 2) Insufficient funding for projects to develop the hydropower industry

Development Program) 2) All the largest HPPs and PSHs belong to one company – PJSC "Ukrhydroenergo" (signs of a natural monopoly) 3) State participation in the capital (the state is the main and sole shareholder of PJSC "Ukrhydroenergo") contributes to the sustainable development of the industry	2) Non-transparency of the national economy, high level of corruption in many areas 3) Inefficient systems of state control over the allocated financing of energy industry enterprises		3) Inflationary processes, rise in price of resources
S (Socio-cultural)		**T (Technological)**	
Positive Factors	Negative factors	Positive Factors	Negative factors
1) The proportion of the working population, attitudes towards work, social mobility 2) The policy of maximum support and development of engineering education, the introduction of the concept of dual education	1) "Brain drain" – many specialized specialists, including those in the field of hydropower, leave Ukraine for other, more economically developed countries 2) Negative public perception of many projects for the construction of new stations and, accordingly, the expansion of land flooding 3) Insufficient level of development of ecological consciousness of the general population in Ukraine	1) The possibility of further development of the industry remains due to the expansion of the use of ecological hydropower potential 2) Separate components of hydropower complexes are quite mobile and can be relatively easily replaced / repaired separately 3) A significant number of small and medium-sized rivers in Ukraine provides an opportunity for further integrated development of the system of small hydropower plants	1) Insufficient experience in the use of foreign advanced technologies for the improvement, support and repair of components of the energy complexes of HPPs and PSHs 2) Scientific and technical research in the field of hydropower in Ukraine is quite limited 3) Weak communication between research teams dealing with new technologies in the field of hydropower and representatives of the business sector of the relevant industry

Separate attention should be paid to what is considered the most important negative factor of the modern environment – the full-scale invasion of the Russian Federation into Ukraine. In the context of this war, the hydropower industry has its own special prospects and risks.

In the context of a total shortage of electricity in the Ukrainian energy system, caused by constant enemy shelling and missile attacks on Ukrainian energy infrastructure facilities, it is the hydropower industry that helps to stabilize the situation and avoid a complete blackout. Of course, HPPs and PSHs at this level of development are not able to replace nuclear and thermal power plants, but during the hours of peak voltages on the power system, the hydropower complex helps to smooth out power surges [11].

The main risks of hydropower in wartime conditions are related to two main aspects:

- rocket strikes and shelling of Ukrainian hydropower facilities;
- occupation of technical complexes (HPPs and PSHs) of the hydropower industry.

As for the first group of risks, it is important to note here that the facilities of the hydropower industry are less prone to large-scale destruction, unlike other energy sectors of Ukraine. The dams of HPPs and PSHs are designed and developed in such a way as to take into account the high water pressure. Rocket warheads, whose weight rarely reaches half a ton, cannot cause total damage to several million tons of stone, from which hydroelectric and pumped storage dams are built. More risks are posed by possible hits in the control centers of hydropower facilities, but for this it is necessary to have high-precision missiles, the insufficiency of which the enemy has repeatedly confirmed by intelligence and practice data [12].

The second group of risks is more significant, since Ukraine cannot exercise control over the objects seized by Russian troops. And in this case, various unfavorable development scenarios can take place: from cutting off the supply of electricity to Ukraine to blowing up the dams of captured objects (unlike missile strikes, such an undermining can be carried out by planting explosives). The most famous example of a hydropower facility seized by the invaders is the Kakhovka HPP, which remains seized as of the end of January 2023. At the moment, this HPP continues to supply a certain amount of electricity to Ukraine (30-40% of its installed capacity), but at the same time cannot participate in voltage stabilization in the Ukrainian energy system at peak times, unlike other industry facilities that are under control of Ukraine [13].

Thus, the sphere of hydropower during the war has its own special prospects and risks of use. However, any war does not last forever and there is a natural question of the development of the hydropower industry in Ukraine in the medium and long term.

Based on the adopted development strategies and scientific research [3, 14], the following principles for the further development of the Ukrainian hydropower industry can be determined:

- adherence to the principles of sustainable development;
- expanding cross-border cooperation;
- construction of new energy facilities in the industry (in particular, small hydropower plants);
- improvement of the regulatory framework for the activities of the hydropower industry in Ukraine, the implementation of the relevant norms of European legislation;

➢ development of state systems of control and environmental monitoring of the hydropower industry in Ukraine.

The main problems of the development of the hydropower industry (risk of man-made disasters, negative impact on the environment, low level of investment activity, development of international cooperation, and so on) and possible ways to solve them are defined in [3].

One of the most important areas for the development of hydropower in Ukraine is to stimulate activities in this industry. To this end, organizational, economic and fiscal incentives can be used. The environmental tax is recognized in international practice as a fiscal instrument for regulating the activities of companies in the context of sustainable development. Let's consider the features and prospects of using this tool in order to develop the hydropower industry in Ukraine.

4.2. Using the environmental tax as a tool to stimulate the development of the hydropower industry in Ukraine

Environmental taxation, as defined by S. O. Nikola and A. O. Husev, is “a set of payments (taxes and fees) levied from legal entities and individuals aimed at stimulating rational environmental management by collecting a certain amount of funds in proportion to the negative impact on the environment …" [15]. The main element of environmental taxation is the environmental tax. This concept refers to a tax levied on activities that have a negative impact on the environment. Of course, not all objectively non-environmental activities are considered subject to environmental taxation – a clear list is determined separately in each country.

According to the generally accepted classification in the EU countries, environmental taxes on the basis of taxation are divided into energy taxes, transport taxes, taxes on environmental pollution, taxes on the extraction and use of natural resources.

In EU countries, energy taxes are several times higher than other groups. The dynamics of collected taxes in the EU countries as a whole is shown in Figure 3.

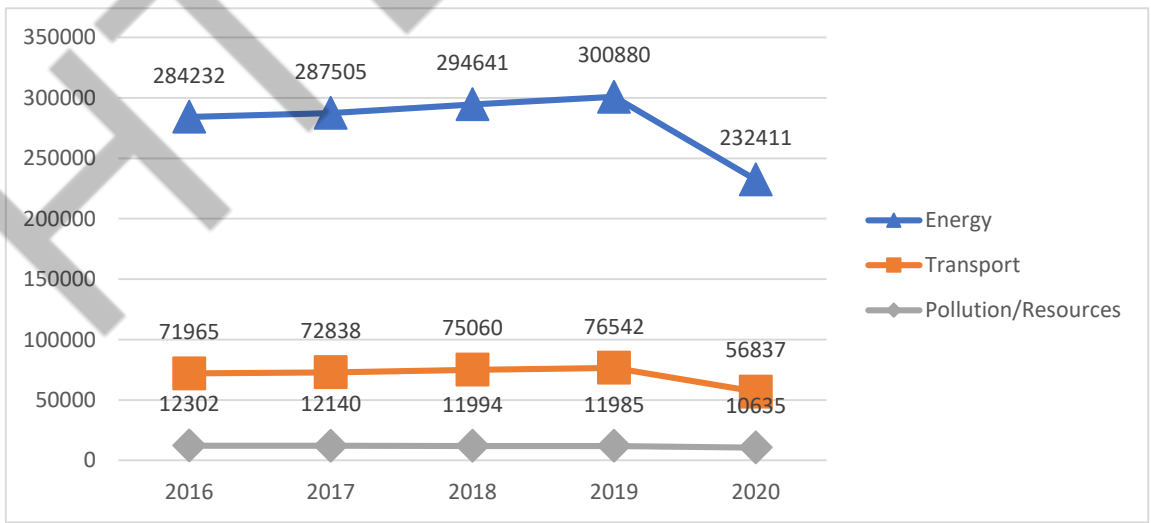

Fig. 3. Dynamics of collected environmental taxes in EU countries, million euros*
*source: developed by the author according to [16-17]

In Ukraine, official statistics give a slightly different grouping of ecotaxes into the following categories: for the amount of harmful emissions into the atmosphere (except for carbon dioxide), for discharges of pollutants into water bodies, for waste disposal, for the formation and storage of radioactive waste, for emissions of carbon dioxide into the atmosphere.

The dynamics of environmental taxes collected in Ukraine is shown in Figure 4. It can be seen that the largest part is formed by taxes equivalent to European energy taxes (harmful emissions into the atmosphere + CO_2 emissions). At the same time, transport taxes in Ukraine do not belong to environmental taxes at all, which may be inappropriate, because the exhaust gases of non-environmental cars have a direct negative impact on the environment. Also, it should be noted that the total amount of collected ecotax in Ukraine on average (2016-2020) is 1.703 times less than the European average, which is definitely a negative manifestation of the domestic fiscal system.

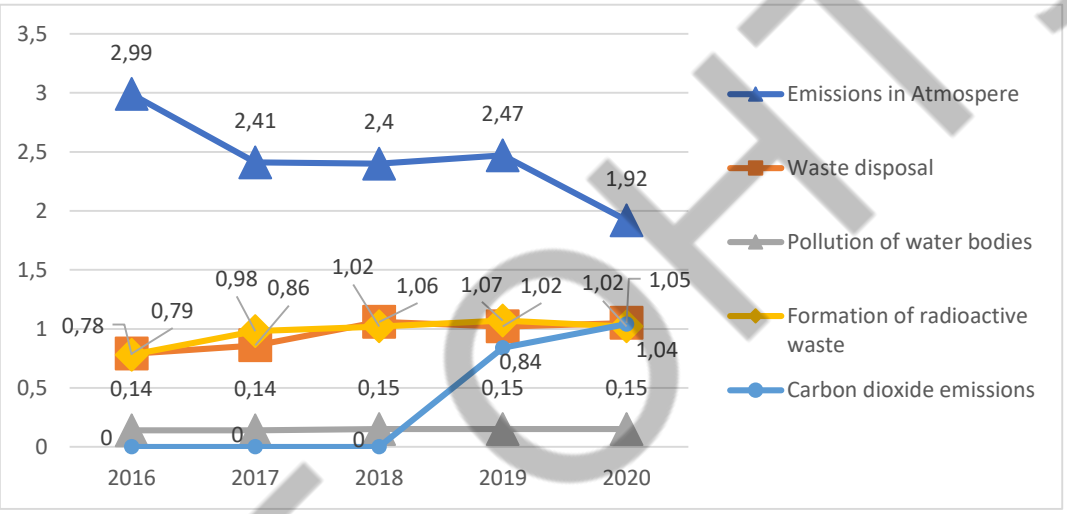

Fig. 4. Dynamics of collected environmental taxes in Ukraine, UAH billion*
*source: developed by the author according to [18]

One of the reasons for the lower volume of ecotaxes collected in Ukraine is their low rate. So, back in the first half of 2021, the tax rate on carbon dioxide emissions was only UAH 10 per ton (for comparison, the similar tax rate in Poland is 1 euro/ton, the UK is 24 euro/ton, France is 36 euro/ton, Sweden – 140 euro/ton) [19]. Under such conditions, the ecotax actually ceased to perform regulatory, stimulating and fiscal functions. But according to the adopted amendments to the Tax code [20], as of January 1, 2022, the ecotax on carbon dioxide emissions is approximately UAH 30/ton and further, by January 1, 2025, this tax will gradually increase to UAH 96.99/ton [21]. The situation is similar with other groups of ecotaxes.

Another reason for the insufficient volume of collected ecotaxes is the weak system of state regulation. The regions – the largest eco-tax payers in Ukraine include the city of Kyiv (1820 million UAH) and the regions: Dnipropetrovsk (857 million UAH), Donetsk (791 million UAH), Lviv (721 million UAH), Zaporizhzhia (434 million UAH), Poltava (262 million hryvnia) – Figure 5. At the same time, the leading regions in terms of harmful emissions into the atmosphere (the tax on this type of pollution occupies the main share of Ukrainian environmental taxation) are the regions (in decreasing order of emissions): Donetsk, Dnipropetrovsk, Ivano-Frankivsk,

Zaporizhzhia, Kharkiv. The incomplete coincidence between the largest polluters and the largest payers of the environmental tax gives grounds to assume that some enterprises are evading the payment of the environmental tax.

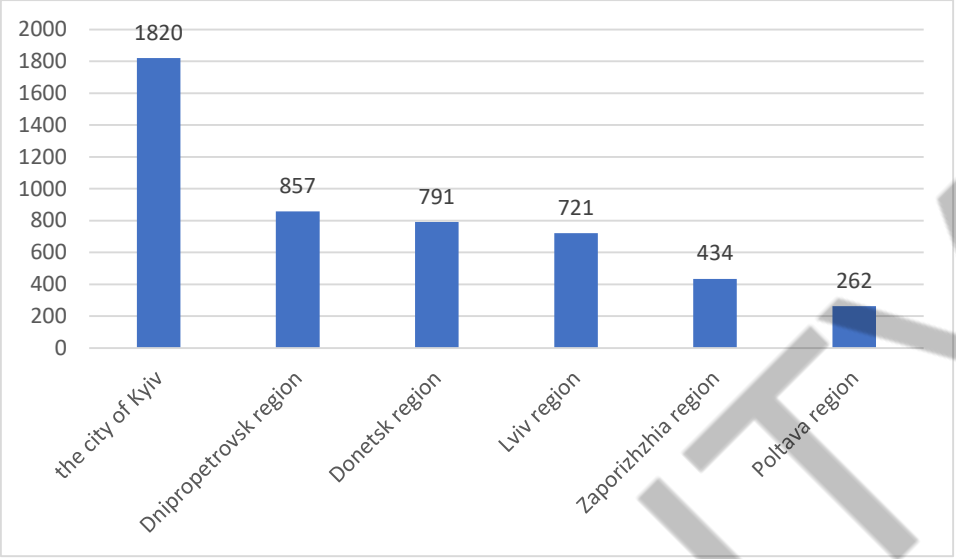

Fig. 5. Dynamics of collected environmental taxes in Ukraine, UAH billion*
*source: developed by the author according to [22]

The problem of misuse of collected funds is also relevant. According to [22], the total revenues from the environmental tax to the state budget for 2021 amounted to 2.8 billion UAH, but only 0.4 billion UAH of which were directed to the implementation of environmental protection measures. It is not clear how other means were used.

Thus, the main directions of development of the national system of environmental taxation are:

✓ changing the structure of environmental taxes, allocation of transport taxes in their structure; introduction of environmental taxes related to the non-environmental use of alternative energy sources;

✓ development of a regulatory framework, strengthening state control over the collection of environmental taxes;

✓ formation of a transparent system for the targeted use of the collected funds for the needs of the organization of environmental protection measures.

The expediency of using the ecotax as a fiscal tool to stimulate the development of hydropower is determined precisely by the described directions for improving the system of environmental taxation. As already noted, the development of hydropower is possible in two aspects:

▪ stimulating the transition from traditional non-environmental energy to alternative sources, in particular, hydropower;

▪ limiting the use of hydropower potential within its environmental component.

Gradual provision of the first direction is possible with the full implementation of the regulatory and stimulating function by the environmental taxation system. Choosing for themselves the most economically viable development option, some potential enterprises in the energy industry, with significant environmental tax costs for companies using traditional energy sources, would opt for alternative sources, in

particular, hydropower. To ensure the fulfillment of the regulatory and stimulating function of the environmental taxation system, it is necessary to establish the appropriate amount of the environmental tax rate and contribute to strengthening state control over the relevant area. And if the necessary legal and regulatory changes are made regarding the size of the tax rate, then the following modernization should be undertaken to strengthen state control:

- ❖ strengthen liability for environmental tax evasion;
- ❖ determine the mechanisms of communication between the sanitary and environmental services for assessing the impact on the environment and law enforcement agencies;
- ❖ improve technologies for detecting harmful emissions from enterprises;
- ❖ organize the sequence and frequency of inspections for compliance with environmental taxation standards.

Such decisions will stimulate the development of hydropower in Ukraine.

At the same time, non-environmental development of large HPPs and PSHs that destroy river ecosystems should also be limited. Preference should be given to SHPPs, which affect the state of water bodies to a lesser extent. In this context, it is possible to introduce certain additional articles of the environmental tax in the context of pollution of water bodies – the specified group of ecotax can be expanded to “negative impact on water bodies”. But the problem is to determine fair criteria for assessing the impact of hydropower facilities on water resources, as well as their boundary values, the appropriate tax rate. Possible criteria for the environmental impact of hydropower facilities on the environment:

- ➢ volumes of additional greenhouse gas emissions caused by the retention of organic matter in water bodies;
- ➢ change in biodiversity indices (Shannon index, Simpson index, etc.) before and after the construction of hydropower facilities;
- ➢ volumes of reduction of fresh water reserves;
- ➢ increase in the water level of water bodies.

Currently, there are almost no technological proposals on the methodology for evaluating these criteria. Their development is one of the promising areas for the development of modern "green" technologies.

Therefore, the environmental tax can act as an effective fiscal tool to influence the development of hydropower. Actualization of the regulatory and stimulating function of ecotaxes will contribute to the development of new hydropower facilities, and the expansion of the environmental taxation system through taxes on the harmful impact of hydropower facilities on the environment can limit the non-environmental development of new hydropower facilities.

V. CONCLUSIONS

This paper examines the current state, conditions, principles, problems and threats to the development of Ukrainian hydropower, as well as the use of fiscal instruments to stimulate the development of this industry. Based on the results of the study, the following conclusions were made:

1. Hydropower is an area of renewable energy, as well as a set of large natural and artificial subsystems that serve to convert the kinetic energy of water into electrical energy. Represented by the United Energy System of Ukraine in the field of hydropower, including 10 HPPs (total capacity 5200 MW), 4 PSHs, 50 SHPPs (total capacity 150 MW). Hydropower actively uses and develops the hydropower potential of Ukraine, which refers to the amount of electricity that can be obtained through the use of water resources. In Ukraine, the hydropower potential has been used only by 62%, but its further expansion should be carried out exclusively within the framework of the environmental component of the hydropower potential.

2. The development of hydropower in Ukraine is influenced by a number of political, economic, socio-cultural and technological factors. One of the most significant among these factors is the functioning of the industry in the context of a full-scale Russian invasion of Ukraine. Under the conditions of a total shortage of electricity in the Ukrainian energy system, caused by constant enemy missile attacks and shelling of Ukrainian infrastructure, the hydropower industry helps to smooth out voltage peaks in the energy system as much as possible and thus avoid a complete blackout. At the same time, the risks of the functioning of the hydropower industry itself in the conditions of war also increased significantly. And if missile attacks on hydropower facilities are capable of causing limited harm to the industry, then the capture of hydroelectric power plants and pumped storage power plants by enemy troops can significantly destabilize the development of the entire industry.

3. An important aspect of the post-war development of the Ukrainian hydropower industry is the stimulation of its activities, which can be carried out through the use of fiscal instruments – environmental taxes, which can be understood as a tax levied on activities that have a negative impact on the environment. The tightening of state control over environmental taxation will contribute to the actualization of the regulatory and stimulating function of the environmental tax, therefore, to an increase in the share of economic entities of alternative energy (in particular, hydropower). At the same time, the development of a system of environmental taxes on water pollution may limit the activities of non-environmental hydropower enterprises.

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3. INFORMATION TECHNOLOGIES, AUTOMATION AND ROBOTICS

OPTIMIZING THE TRAJECTORY OF THE QUADCOPTER USING BUILT-IN SENSORS

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Abstract. *The task of optimizing the movement of a quadcopter using built-in sensors is considered. This is done using modern geolocation algorithms.*

Key words: *Algorithms, movement.*

I. INTRODUCTION

A quadcopter is an unmanned aerial vehicle with four main rotors that rotate diagonally in opposite directions. The rapid development of multicopters began in this century, but already as unmanned aerial vehicles.

Due to the simplicity of the design, multicopters have become very popular among modeling enthusiasts. Cameras and GPS modules are installed on them, which makes it possible to conduct high-quality video recording of the area from a height. Multicopters are small in size and weight, they are maneuverable, relatively cheap and easy to use. These possibilities are used not only for ordinary video recording, but also in many other places. Already today, multicopters can be seen in rescue services, research work, delivery of small cargo, and so on.

The compass serves so that the aircraft can orient itself in space, and has the ability to fly in "headless" mode. Additionally, a GPS module is attached to the aircraft. Usually, the compass is already built into the GPS module.

The accuracy of geolocation depends on a number of factors, including navigation satellite equipment errors, GPS receiver errors, and satellite signal propagation errors. In general, the geolocation accuracy for a household GPS receiver is about 15 meters. The sources of errors can be the following reasons:

- insufficient number of visible satellites;
- inaccuracy of ephemerides and errors of satellite clocks
- interference of the reflected signal to the antenna of the satellite receiver; obstacles associated with changes in the conditions for receiving signals from satellites (passing through a tunnel, densely built-up area, forest area);
- time delay in the receiver equipment;
- problems related to the power supply of the navigation device (power loss of the terminal or strong interference from the power grid to the terminal equipment);
- ionospheric delay;
- tropospheric delay.

At the current stage of technology development, mobile devices have become widely distributed. A large number of which have a built-in GPS receiver. Today, personal GPS monitoring is used in many areas of activity, so the problem of storing a large amount of recorded GPS data is relevant.

Reducing the amount of geolocation data can be achieved by applying various algorithms for processing received navigation data.

II. LITERATURE ANALYSIS

A GPS receiver is a radio receiving device designed to determine the geographic coordinates of one's current location using signals from artificial satellites of the corresponding GPS system.

The principle of operation consists in calculating the position based on the measurement data of the propagation time of radio signals emitted by artificial satellites to the receiver antenna and on the basis of information about the position of each satellite in orbit. In existing systems, data on the orbits of all satellites are transmitted periodically and stored in the receiver's memory. This is the so-called almanac.

2.1. Ramer-Douglas-Packer algorithm.

The Douglas-Packer algorithm is an algorithm that reduces the number of points on a curve approximated by a larger series of points. The algorithm is also known by the following names: the Ramer-Douglas-Packer algorithm, the iterative nearest point algorithm, and the split-and-merge algorithm.

The essence of the algorithm is to construct a kink with a smaller number of points from a given kink, approximating the curve. The algorithm determines the discrepancy, which is calculated by the maximum distance between the original and simplified curves. A simplified curve consists of a subset of points that are determined from the original curve.

The initial curve is an ordered set of points or lines, and a given distance $\varepsilon > 0$. The initial curve 0 and the simplified curve 4 are shown in Fig. 1.

The algorithm recursively divides the line. The input of the algorithm is the coordinates of all points between the first and the last. The first and last points are kept unchanged. After that, the algorithm finds the point furthest from the segment connecting the first and last points. If the point is at a distance smaller than ε, then all the points that have not yet been marked before saving can be thrown out of the set and the new straight line smooths the curve with an accuracy not lower than ε.

If the distance is greater than ε, then the algorithm recursively invokes itself on the set from the initial to the given and from the given to the final points (which means that the given point will be marked before saving).

At the end of all recursive calls, the output polygon is built only from those points that were marked before saving.

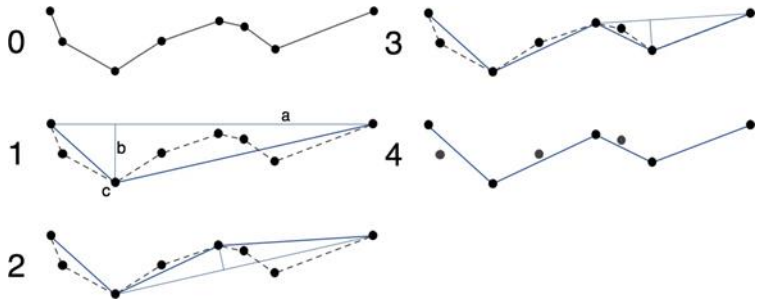

Fig. 1. Smoothing of the piecewise linear curve by the Douglas-Packer algorithm.

2.2. Kalman filter.

A Kalman filter is an algorithm that uses sequences of measurements over time that contain noise (random deviations) and other inaccuracies and produces estimates of unknown variables that are potentially more accurate than those based on measurements alone. More formally, the Kalman filter operates recursively on streams of noisy input data, and produces a statistically optimal estimate of the base state of the system. The filter is named after Rudolf Kalman, one of the main developers of its theory.

The Kalman filter has numerous applications in technology. Applications for guidance, navigation and control of vehicles, especially aircraft and spacecraft, are common. In addition, the Kalman filter is a widely used concept in time series analysis, used in fields such as signal processing and econometrics. Kalman filters are also a major topic in robotic motion planning and control, and are sometimes included in trajectory optimization.

This algorithm works as a two-step process. In the prediction step, the Kalman filter outputs estimates of the current state variables, along with their uncertainties. Once an observation of the output of the next measurement is obtained (surely distorted to some extent by deviation, including random noise), these estimates are refined using a weighted average, in which more weight is given to estimates with higher certainty. Due to the recursive nature of the algorithm, it can run in real time using only the available input measurements, the precomputed state, and its uncertainty matrix; no additional information is required.

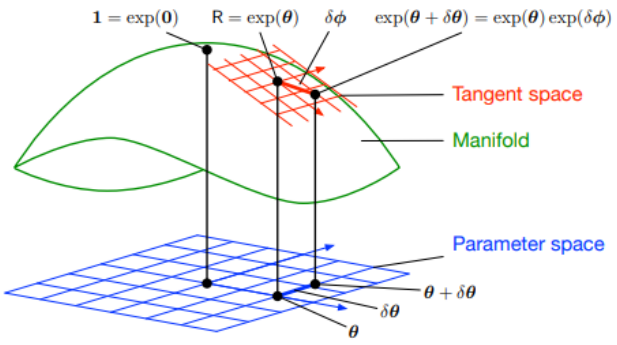

Fig. 2. Process of the Kalman filter

Application of EKF. The state area consists of 10 variables:

$$x_t := \left(x_t, y_t, z_t, \dot{x}_t, y_t, \dot{z}_t, \Phi_t, \Theta_t, \Psi_t, \dot{\Psi}_t\right)^T \in \mathbb{R}^{10} \quad (1)$$

where (x_t , y_t , z_t) denotes the current position of the quadcopter in meters and speed in meters per second in world coordinates, roll Φ_t , pitch Θ_t , search Ψ_t and angular velocity $\dot{\Psi}_t$ in degrees/s. In addition to each sensor, the observation function h (x_t), which describes how the vector of observations z_t is calculated from the output data of the sensors.

The quadcopter measures its horizontal $\hat{v}_{x,t}$ and $\hat{v}_{y,t}$ their local coordinates, which are transformed into global ones $\dot{x}_t$ and $\dot{y}_t$. Roll angle $\hat{\Phi}_t$ and pitch $\hat{\Theta}_t$, measured by the accelerometer, are direct measurements of Φ_t and Θ_t in accordance. To calculate the drift of the search, the differentiation of the height measurement is carried out $\hat{h}_t$ and rummaging $\dot{\Psi}_t$and we consider them observations of the corresponding velocities. Therefore, the observation function and the measurement vector can be written as

$$h_t(x_t) := \begin{pmatrix} \dot{x}_t \cos\Psi_t - \dot{y}_t \sin\Psi_t \\ \dot{x}_t \sin\Psi_t - \dot{y}_t \cos\Psi_t \\ \dot{z}_t \\ \Phi_t \\ \Theta_t \\ \dot{\Psi}_t \end{pmatrix}; \quad (2)$$

$$z_{t,t} := \left(\hat{v}_{x,t}, \hat{v}_{y,t}, \frac{\hat{h}_t - \hat{h}_{t-1}}{\delta_{t-1}}, \hat{\Phi}_t, \hat{\Theta}_t, \frac{\dot{\Psi}_t - \dot{\Psi}_{t-1}}{\delta_{t-1}}\right)^T, \quad (3)$$

where δt denotes the time that has passed from the moment t to t + 1.

When the PTAM successfully tracks a video frame, the scale of the quadcopter's position in space is first determined through the scale factor λ * and converted to the quadcopter's local coordinate system using direct observations of the current position, which is given as

$$h_P(x_t) := (x_t, y_t, z_t, \Phi_t, \Theta_t, \Psi_t,)\, T ; \quad (4)$$

$$z_{P,t} := f(E_{DC} E_{C,t)}, \quad (5)$$

where $E_{C,t} \in SE(3)$ is calculated position cameras (scaled with λ); $E_{DC} \in SE(3)$ is static transformation with coordinate systems camera on coordinate system quadcopter, and $f : SE(3) \rightarrow \Upsilon^6$ transformation with of space SE (3) to presentation roll - pitch - yaw.

The prediction model shows how the state vector xt changes over time. In particular, the horizontal acceleration of the quadcopter is approximated. $\ddot{x}, \ddot{y}$, based on the current state of x^t – and the vertical acceleration is calculated $\ddot{z}$, acceleration of the rotation of the

probe $\dot{\Psi}$ and roll speed $\dot{\Phi}$ and pitch $\dot{\Theta}$ based on the combination of the current state xt and the active control state u ^{t} .

The horizontal acceleration is proportional to the horizontal force acting on the quadcopter, which is given by

$$\begin{pmatrix} \ddot{x} \\ \ddot{y} \end{pmatrix} \propto f_{уск} - f_{сопр} \quad (6)$$

where f $_{ref}$ denotes the braking force, and f the accelerating force. The drag force has a linear and quadratic part corresponding to laminar and turbulent flows - by setting the quadcopter at a relatively low speed, we can approximate a pure linear function to the current horizontal speed. Accelerating force f $_{usc}$ proportional to the projection of the z - axis of the quadcopter on the horizontal plane The above can be imagined as

$$\ddot{x}(x_t) = c_1 R(\Phi_t, \Theta_t, \Psi_t)_{1,3} - c_2 \dot{x}_t; \quad (7)$$

$$\ddot{x}(y_t) = c_1 R(\Phi_t, \Theta_t, \Psi_t)_{2,3} - c_2 \dot{x}_t, \quad (8)$$

where R (•) $_{i,j}$ means entries in the rotation matrix determined by roll, pitch, and yaw angles.

This model implies a constant thrust of all four rotors. The effect of outgoing control commands is also approximated. $u_t = (\bar{\Phi}_t, \bar{\Theta}_t, \bar{\dot{z}}_t, \bar{\dot{\Psi}}_t)$ using a linear model:

$$\dot{\Phi}(x_t, u_t) = c_3 \overline{\Phi}_t - c_4 \Phi_t; \quad (9)$$

$$\dot{\Theta}(x_t, u_t) = c_3 \overline{\Theta}_t - c_4 \Theta_t; \quad (10)$$

$$\ddot{\Psi}(x_t, u_t) = c_5 \bar{\dot{\Psi}}_t - c_6 \dot{\Psi}_t; \quad (11)$$

$$\ddot{z}(x_t, u_t) = c_7 \bar{\dot{z}}_t - c_8 \dot{z}_t. \quad (12)$$

Coefficients c $_{3}$ ... c $_{8}$ determined by test flights of the quadcopter. The general state of the system is given as

$$\begin{pmatrix} x_t+1 \\ y_t+1 \\ z_t+1 \\ \dot{x}_t+1 \\ \dot{y}_t+1 \\ \dot{z}_t+1 \\ \Phi_t+1 \\ \Theta_t+1 \\ \Psi_t+1 \\ \dot{\Psi}_t+1 \end{pmatrix} \leftarrow \begin{pmatrix} x_t \\ y_t \\ z_t \\ \dot{x}_t \\ \dot{y}_t \\ \dot{z}_t \\ \Phi_t \\ \Theta_t \\ \Psi_t \\ \dot{\Psi}_t \end{pmatrix} + \delta_t \begin{pmatrix} \dot{x}_t \\ \dot{y}_t \\ \dot{z}_t \\ \ddot{x}(x_t) \\ \ddot{y}(x_t) \\ \ddot{z}(x_t, u_t) \\ \dot{\Phi}(x_t, u_t) \\ \dot{\Theta}(x_t, u_t) \\ \dot{\Psi}_t \\ \ddot{\Psi}(x_t, u_t) \end{pmatrix}. \quad (13)$$

The model described in formulas (7)–(13) does not pretend to be physically correct due to numerous assumptions, but works very well in practice, mainly due to its completeness: the behavior of all state parameters and the action of all control commands are approximated, allowing "blind » forecast, that is. forecast without observations for a short period of time (~125 ms in practice).

A number of experiments were conducted to analyze the properties of the obtained system. They were conducted in different environments - in rooms of different sizes and appearance, as well as outdoors under the influence of sunlight and light wind.

2.3. Moving average.

Moving average or moving average is one of the analysis tools random processes and hours rows, what consists of in calculations average subsets values Sliding average not is scalar, and is random process Size subsets, from which is calculated average the value can be either constant or variable. A moving average can have weights, for example, to increase the impact of more recent data compared to older

Sliding average maybe to calculate from arbitrary data, however, most often him use in analysis hours rows for smoothing sudden fluctuations and emphasizing long-term trends or cycles. WITH mathematical points vision sliding average is variety convolutions and looks like on low pass filter in signal processing.

Simple sliding mean (SMA) — is alone with most simple ones and popular indicators in technical analysis SMA is ordinary average arithmetic from the values for a certain period. SMA refers to the class indicators that follow the trend, it helps to determine the beginning the new trend and its completion can be determined by its angle of inclination strength (speed movement), it same in quality foundations (or smoothing factor) is applied in big quantity others technical indicators.

2.4. Method of fast filtering of GPS data.

GPS receivers are devices that continuously calculate position, time and a number of other parameters. In its pure form, GPS data is inconvenient to use and often carries a lot of redundant information. Even if the receiver is in a stationary state, the position data is constantly changing, there is a kind of noise associated with the movement of satellites, processes in the atmosphere and radiation from the sun, which affect the signal. If you do not use filtering and take position data from a stationary receiver as is, you can observe a continuous change in its position, as shown in Fig. 3. As a result of such changes in half an hour of immobility, the calculated path of the observed object can reach several kilometers, which may be unacceptable for a number of systems.

In complex monitoring systems for collecting and storing GPS data from many objects, the use of filtering allows you to significantly reduce the volume of processed information without losing the quality of the latter. This filtering task consists in screening out data that do not provide fundamentally new information about the state of the object.

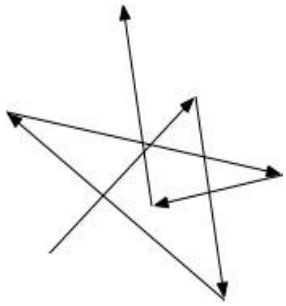

Fig. 3. An example of noise.

The proposed GPS data filter can be divided into two parts:

- pre-cleaning filter;
- redundant data filter.

Pre-filtering implements screening of samples that are erroneous, incomplete or do not correspond to the number of required parameters. For a number of systems, this stage of filtering can be useful. Additionally, depending on the data quality requirements, it is possible to screen out samples in which the accuracy values exceed the maximum permissible limits specified in the filter settings.

The redundant data filter uses the distance between two points as a criterion, which must be less than the sum of their positioning accuracies. For longitude and latitude, this is the radius of the circle (of the sphere, if the height is taken into account), which is taken equal to the precision value for the given point. New samples are filtered, provided that their circle does not intersect with the circle of the previous, filtered sample. If this type of filtering is not performed, then in addition to extra points without useful information, noise will be observed.

The main advantages of this method of filtering GPS data can be noted:

- the possibility of implementing the algorithm on a low-power device;
- significant reduction in data flow.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

All quadcopters have a similar operating principle. Since they belong to aircraft, all the laws of aerodynamics also have their influence on their operation. In the theory of flight (aerodynamics), it is customary to distinguish three axes of rotation, which determine the orientation and direction of the aircraft's motion vector. These three axes are called roll, pitch, and yaw.

Roll is a turn of the device around its longitudinal axis (the axis that runs from the nose to the tail). Pitch is a turn around the transverse axis (tilts the nose, raises the tail). Yaw is a turn around a vertical axis, most similar to a turn in the "terrestrial" sense.

The quadcopter has another fourth indicator - Gas (Throttle). It determines the speed of movement along the vertical axis by increasing or decreasing the speed of the motors.

The design of the quadcopter provides it with the ability to fly due to the placement of the main propellers in the correct order. If you do not follow this order, take-off will be

impossible. So, in order for the quadcopter to be able to take off, it is necessary to perform the following placement scheme:

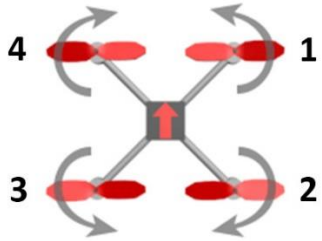

Fig. 4. Direction of rotation of all four screws

As you can see from the picture, each motor rotates in its own direction. For proper operation, motors 1 and 3 must rotate counterclockwise, and motors 2 and 4 must rotate clockwise. It is also possible to do the opposite, that is, 1 and 3 - clockwise, and 2 and 4 - counterclockwise.

To ensure rotation along each of the axes, the quadcopter must tilt in the required direction. Leaning forward, toward the nose, or vice versa, backward is pitch. A tilt to the left or right is a roll. If the quadcopter performs a turn around the vertical axis, then it will be a yaw.

To ensure tilting to one side, it is necessary to change the speed of the motors. When one of the motors starts rotating faster than the others, it starts to lift the aircraft up, but since the other motors are not spinning fast enough, it will tilt in the opposite direction to this motor. So, to create a forward pitch, motors 2 and 3 need to rotate faster than motors 1 and 4. In the case where a yaw is required, motors 1 and 3 need to rotate faster than 2 and 4 if it is a left rotation, and for rotation to the right, 2 and 4 should be faster than 1 and 3.

However, this is not enough to ensure stable movement. Unfortunately, the quadcopter is affected by many other factors that make its movement unstable. Such factors include: strong air, excess weight, asymmetric placement of components. This is where the GPS module comes to the rescue.

IV. RESULTS

After analyzing the work of implemented GPS data processing algorithms, they can be divided into two groups:

- algorithms that reduce the amount of data;
- algorithms that improve data accuracy.

The filters of the first group, which allow to reduce the amount of data, include the Douglas-Packer algorithm and the method of fast filtering of GPS data. The Kalman algorithm and the moving average belong to the filters of the second group, which allow improving the accuracy of navigation data.

As a result of the processing of GPS data by filters of the first group, the number of points is significantly reduced, but the accuracy of the route itself decreases. As a result

of data processing with filters of the second group, the accuracy of the track improves, but the amount of data remains unchanged. Therefore, the use of several processing methods was proposed.

The GPS data was processed by various combinations of algorithms. Test GPS data was processed by different algorithms sequentially, while the order of algorithms and their number gives different results. Table 1 shows the processing data of two different sets of GPS data using different combinations of processing algorithms.

Table 1. Evaluation of the degree of similarity of objects

A combination of algorithms	**Data set #1**		**Data set #2**	
	Number of points	Average accuracy, m.	Number of points	Average accuracy, m.
—	66	6.05	128	5.97
Kalman Douglas-Packer	9	6.04	11	5.97
Douglas-Packer moving average	10	6,12	15	6.04
Quick filter. Kalman	44	6.35	80	6.33
Quick filter. Moving average	43	6.61	79	6.23
Quick filter. Kalman Douglas-Packer	6	6.98	11	6.75
Quick filter. Douglas-Packer moving average	7	6.28	8	6.92

Using a combination of the Kalman and Douglas-Packer algorithms showed the best result. This combination made it possible to increase the accuracy of the received GPS data and reduce their number.

V. CONCLUSIONS

Kalman, Douglas-Packer, moving algorithms are considered in the work average and fast filtering method of GPS data. For results GPS data processing, these algorithms can be divided into two groups. The first group algorithms, to which refers to algorithm Kalman and movable means allows to improve accuracy received navigational dataThe second group of algorithms, which includes the Douglas-Packer algorithm and method of fast filtering of GPS data, allows to reduce the number of GPS-data

It was conducted analysis work different combinations these algorithms, When GPS data are processed different algorithms successively. On based on the analysis of the received processing results, the best result has a combination of Kalman and Douglas-

Packer. Using this combination when processing GPS data, makes it possible to reduce the amount of data that necessary save, without reduction accuracy information about location which they contain

using this one combination algorithms, was developed module, which allows you to process GPS data for further use and storage.

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RESEARCH OF MECHATRONIC GRIPPER DEVICES ON THE BASIS OF BIONICS WITH EXTENDED FUNCTIONAL CAPABILITIES

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Annotation: *Moving complex packaging designs, created on the basis of the use of new packaging materials with improved physical and mechanical characteristics requires the development of new designs of gripping devices with enhanced functionality. This task is currently very relevant and can be solved by creating a new philosophy of designing such objects, which is based on the principles of bionics.*

The authors consider the advantages and disadvantages of using the design of gripping devices created on the basis of bionics with extended functionality for the performance of technological packaging operations. The opinion is expressed that fingers have the simplest design for finger gripping devices, which are created using the technology of an elastic loop, which was borrowed from the structure of the tail fin of a fish and has the name «Fin Ray® Effect»

An improved design of the finger of a mechatronic gripping device with an effect is proposed «Fin Ray®». Investigation results concerning the following catching device functional characteristics and reconstructing fingers of the contour of the generator surface of different objects by the working platform with possibility to fix them additionally banding fingers' ends on the object block are suggested.

The results of an analytical and experimental study of the durability and quality of the structural elements of the finger gripping device with the effect are presented by «Fin Ray®», made of various polymer materials.

It was established that finger samples made of PET material are characterized by the greatest functional capabilities. The printed fingers showed stable performance within 80,000 cycles. Its further use leads to a slow decrease in stiffness and load. The destruction of the sample occurs around 200,0000 cycles.

Keywords: *Mechatronic gripper device, bionics, «Fin Ray®» effect, gripping the object, changing the effort.*

I. INTRODUCTION

Recently, revolutionary changes have been observed in the designs of modern gripping devices. They are associated with the active emergence of new structural materials with improved physical and mechanical characteristics and technologies for creating complex structures using 3D printers. However, even these factors are only part of the forces that led to the emergence of a new philosophy of design and function of gripper devices. This idea is based on the principles of bionics.

The word "bionics" was proposed by Jack Steele, probably from the Greek βίον - "unit of life» and the suffix -ic «-similar», i.e. "bionics" means «life-like».

A science that studies the structure and functioning of living organisms, used to solve engineering problems, creation of new devices and mechanisms is called bionics (from Greek bios «Life»). The designs and methods of gripping objects by living organisms (animals and humans) led to the emergence of a new generation of gripping devices for the packaging industry.

Designs of devices can be conditionally divided into three groups.

The first group includes adaptive gripping devices that imitate the work of human fingers or animal tentacles.

An example of such devices is a three-finger gripper with three phalanges. The design of the gripping device and its operation is built on the basis of researching the operation of the fingers of the human hand. Unlike the existing finger gripping devices, the new generation has two significant advantages: precise adjustment of the clamping force of the object and complex movement of the fingers, which provide an additional opportunity to manipulate various forms of packaged objects, taking into account the change in their dimensions and the texture of the packaged material and product, as well as managing the complex position of the packaged objects in space.

Such gripping devices are ideal for creating packaging equipment of the fifth generation - robotic packaging complexes with their subsequent integration into the production of the future - Industry 4.0

The second group includes frameless adaptive gripping devices that imitate the work of elastic organs, such as animal tentacles. Such gripping devices were called «soft hands». The main difference is the absence of a frame and the use of soft materials, various types of windings, etc. The "soft" structure of the gripper allows to ensure the necessary flexibility of the tentacles and their adaptability to the shape of the packed object, uniform distribution of the clamping force over the entire contact surface. An example of the use of vacuum in the control of frameless gripper devices is a design that imitates the operation of an octopus tentacle. They do not have a skeleton and are almost entirely made of soft muscles, which provide them with extreme flexibility and maneuverability. It can be stated that the main advantages of frameless gripping devices include the ability to gripper and hold packaged objects of arbitrary shaped and rigidity.

The third group of gripper devices differs from the previous two and is created by simulating phase transitions of granular materials when the amount of external influence changes. Although it should be noted that this principle of operation resembles, for example, the work of a chameleon's tongue, which is able to catch various insects by reliably grabbing the appropriate prey with its tongue. The basis of the design idea was the well-known vacuum packaging of coffee, which has a high hardness. But as soon as you break the integrity of the package, it becomes soft and pliable. By placing such a gripper, in its softened state, on any packaged object, it can be made to follow the shape of the object's surface. After that, the air is pumped out of the internal space of the gripper,

the gripper device hardens and reliably grippers the packaged object of a rather complex shape, which can subsequently be lifted, moved and held without violating its integrity.

II. ANALYTICAL REVIEW OF LITERATURE

Recently, a lot of attention has been paid to issues related to the development of equipment for creating packaged products and forming structural elements of group or transport packaging from them [1-4]. In general, the technological processes of the formation of group and transport packaging are an integral part of the automated lines of any enterprise [1,4]. For example, works [5-8] describe the designs of equipment for packing products and provide methods for calculating individual working bodies of mechanisms and devices. However, in these works, little attention was paid to the layout equipment methods based on the mechatronic approach using gripper modules and there are no methods of selection of executive mechanisms taking into account the methods and forms of their control. We may combine into aspecial group the works that describe the methods and principles of selecting gripping devices for the packaging industry [9, 10]. However, these methods need to be supplemented and clarified within the use of new packaging materials, reduction in their thickness and increase in the variety of forms of packaged products.

Studies of the kinematics and dynamics of gripping devices, as the main elements of industrial robots, methods of developing their control algorithms, and other automation issues are given in works [11-14]. However, the given designs of gripping devices and schemes of manipulators are used for technological operations only with unpackaged metal products and have limited use in packaging equipment.

The question of automation of technological processes with the use of devices for manipulating artificial objects on the basis of bionics are dedicated works [15-19]. The works consider the design of a new generation of robot elements and gripping devices based on bionics. Compressed air is used as a working agent for such devices. The given methods of calculation and selection of pneumatic gripping devices do not fully take into account the physical and mechanical properties of the packaged product and can only be used approximately for the design of pneumatic gripping devices in the packaging industry.

III. OBJECT, SUBJECT AND METHODS OF RESEARCH

The purpose and tasks of the research: development of the scientific and technical foundations of the creation of the structure of the mechatronic module of the gripping device on the basis of bionics with extended functional capabilities.

This goal is realized by solving the following problems:

- to conduct analysis of technological schemes and existing samples of robotic complexes for group packaging of food products in order to determine the features of the

technological process of forming group packaging, typical designs of mechanisms and devices;

- to create a new design of a mechatronic module of a gripping device based on bionics for group packaging operations with enhanced functionality;
- to provide the new design of the mechatronic module with the ability:
  - reliable gripper and retention of packages of various shapes;
  - preservation of the commercial appearance of packages with a food product in the process of their movement;
  - system of redistribution of holding force between gripping elements;
  - to produce an experimental installation of a mechatronic gripper module based on bionics for performing group packaging operations with extended functionality and to verify its functionality in accordance with the research objectives.

Object of study: the process of gripping packaged objects by a mechatronic gripper device based on bionics and the relationship between its structural, kinematic and dynamic parameters to expand functionality.

Subject of study: constructive implementation of a mechatronic gripping device based on bionics.

Research methods - theoretical studies were carried out using complex methods, taking into account the mechatronic-modular construction of gripping devices. To analyze the geometric, kinematic and dynamic parameters of the operation of the mechatronic gripping device on the basis of bionics the basic laws of mechanics, the theory of thermo- and gas dynamics for power pneumatic drives were used. Experimental studies were carried out using the theory of experiment planning and mathematical statistics, the methodology of an active experiment and with the help of pressure sensors, displacement, effort and loss, a block of analog-to-digital converters, a computer and software packages: Labview, FluidLab_PA. Experimental data processing and calculations were performed in Microsoft Excel, MathCad and Autodesk Inventor software packages.

IV. WORK RESULTS

4.1 Mathematical modeling of the process of gripping packaged objects by a mechanical gripper device based on bionics.

The mathematical model of the process of gripping consumer packages with a mechanical gripping device based on the principles of bionics was based on the use of subsystems of a flexible gripper and a robotic arm. The mathematical model was developed on the basis of the Denavit-Hartenberg model [16]. The grip force ranges were determined during the analysis of similar technical grip systems [11,12]. It was assumed that the created mathematical model describes the change of forces in the gripping device required for the robotic system during the movement of the consumer package by the flexible gripping device.

DH displacement matrices were created to model the system. It was assumed that a six-by-six matrix contains three rotational and three translational movements, and a four-by-four matrix contains two rotational and two translational movements. The formed forces generated during the movement of the gripping device can be described using the Lagrange torque model, (Fig. 4.1) The resulting mathematical model describes the influence of the inertia component A, the Coriolis force component C, the centripetal component B and the gravitational component G. The calculation of the force vectors was determined using equation (1).

$$A(q)[\ddot{q}] + B(q)[\dot{q}q] + C(q)[\ddot{q}] + G(q) = \tau \quad (4.1)$$

where, q is a vector of connection angles. A (q) is a symmetric, bounded, positive definite inertia matrix . C (q) - Coriolis forces. B (q) - centripetal forces. G (q) - gravitational force. τ - is the drive torque vector.

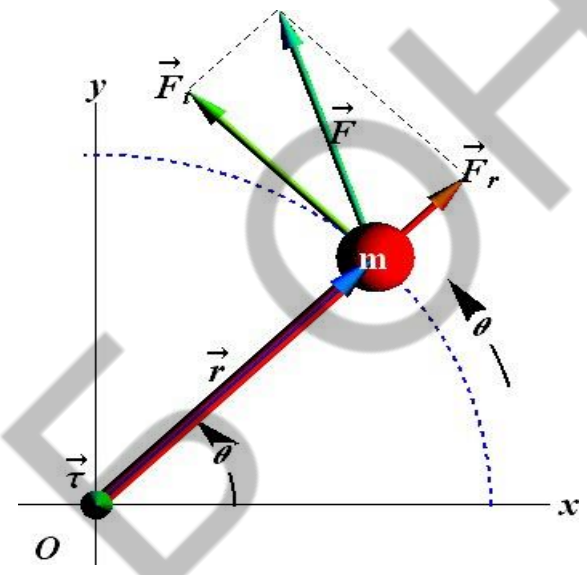


Fig. 4.1. A model of the distribution of forces during the movement of an object by a robotic arm

The quality of gripping and holding the moving object depends on the kinematic and dynamic characteristics of the movement of the gripping device and the reliability of its design [13, 14].

The objective of the analytical studies of the design of the gripping device was to investigate the reliability and durability of the operation of the finger of the gripping device. For this purpose, the shape and design of the proposed finger was used during modeling of its movement in the Autodesk Inventor program (Fig. 4.2).

The virtual model of the gripping finger during bending provided the pressing force of up to 13 N along the X-axis. The maximum reduction in size when rotating the finger along the x axis was up to 9.45 mm.

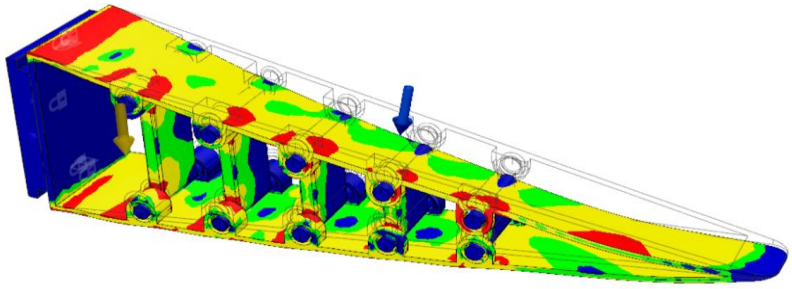
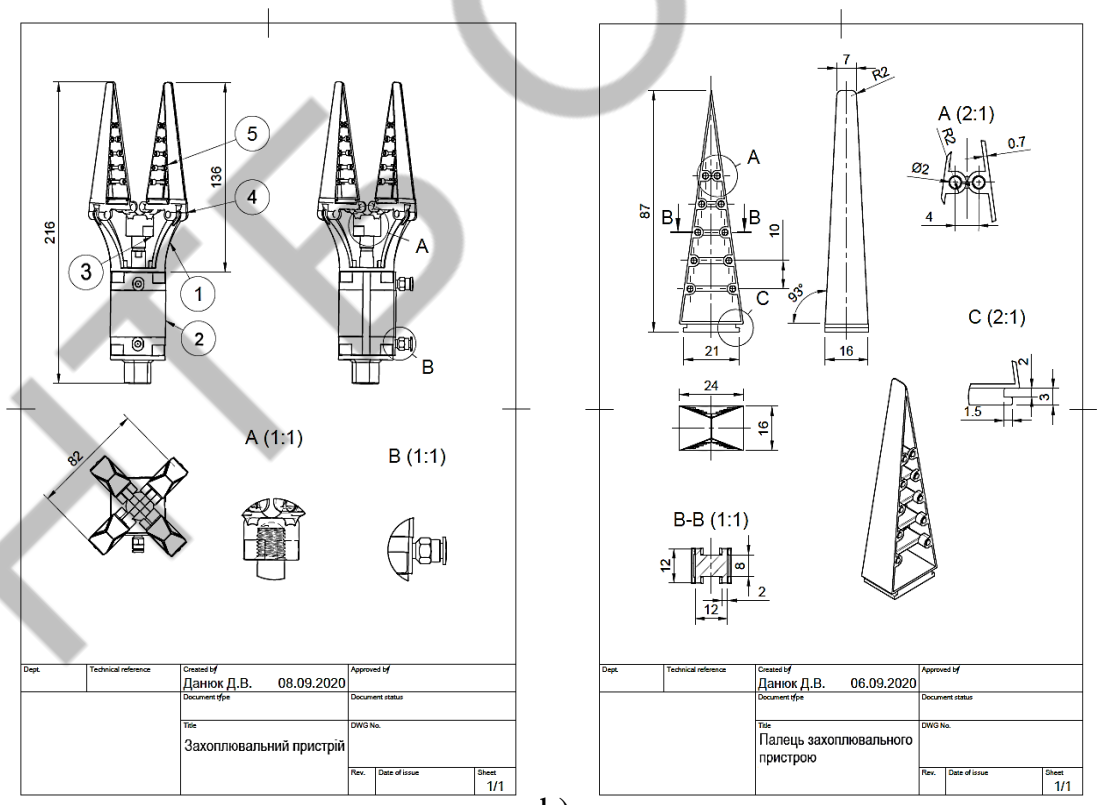


Fig. 4.2. Zones of stress distribution during bending of the finger of the gripping device

The resulting deformation of bending and stretching of the structural sections of the finger work in the form of stress changes is shown in fig. 4.2. Areas highlighted in red have the greatest deformation. In the future, it can be assumed that it is in these zones that the destruction of the elements of the finger will begin. To reduce bending stresses, the shape of the finger construction elements was optimized.

4.2 Development of technical documentation of the mechatronic module of the gripping device on the basis of bionics.

According to the results of the analysis of gripping devices based on the principles of bionics, a four-finger gripping device with flexible finger surfaces was proposed and subsequently designed in the "compass" program (Fig. 4.3).



a) b)

Fig. 4.3. Design of a four-finger gripping device with flexible fingers: a - working drawing of the general view; b - working drawing of a finger of the gripping device

The design of the four-finger gripper consists of a body 1, to which a pneumatic cylinder 2 is rigidly fixed in the lower part. In the upper part of the case, on the hinges 3, four fixing plates 4 are fixed for holding the fingers 5. The inner side of the fingers 5 acts as the working surface of the grip. The rear parts of the fixing plates 4 are attached to the bar 7 through the hinges 6, which is rigidly connected to the rod of the pneumatic cylinder 2. The module of the gripping device is connected to the mechanism of moving the robot through an additional cover 8, which is fixed on the back of the cylinder 2.

The main element of the design of the mechatronic module of the gripping device is the fingers. Their design involves the use of two flexible flat polymer plates of a given width, which are connected to each other in the shape of a triangle. Special stiffeners are provided in the middle of the triangle to stiffen the structure. Each rib is attached by two hinges to the surface of the generatoring plates. This design of the finger provides great elasticity when bending the surfaces of the plates.

An experimental installation was made according to the working drawings. The design of the experimental setup consists (Fig. 4.4) of plate 1, to which rack 2 is rigidly fixed in the lower part. In the upper part of the rack 2, a rotation module 3 with a fixation angle ranging from 0° to 90° is attached to the hinge. The device for moving the gripping device 4 is attached to the rotation module 3. Experiments were conducted on gripping devices with different types of drives: servo and pneumatic (Fig. 4.4).

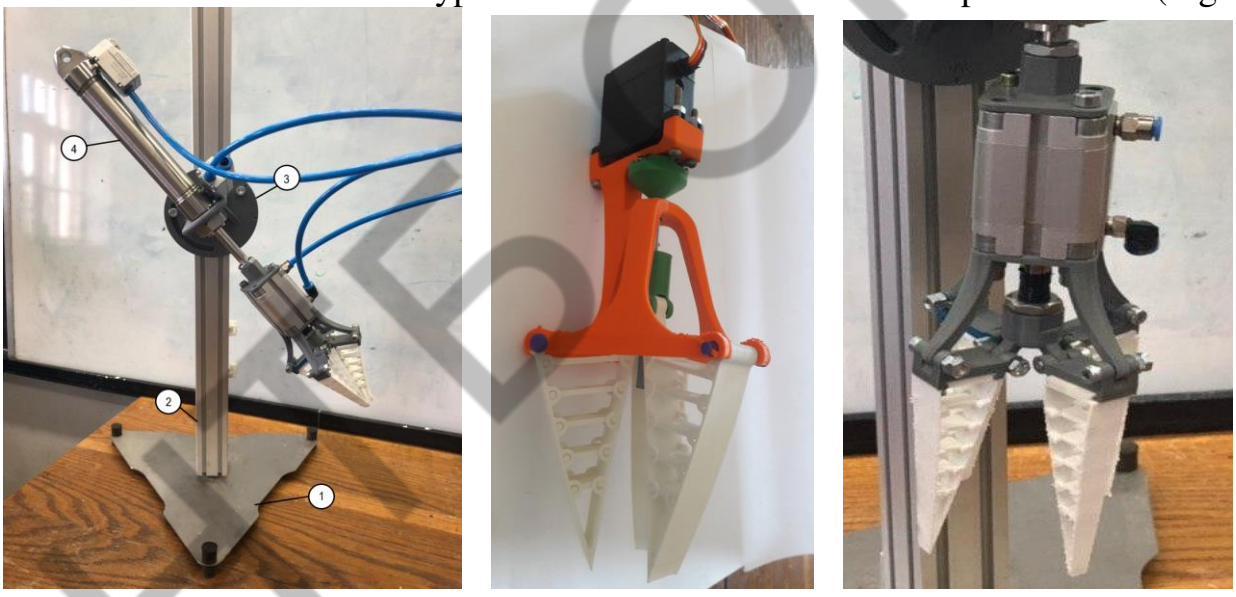


Fig. 4.4. The design of the experimental installation of the mechatronic module of the gripping device is based on the principles of bionics: 1 - plate; 2 - rack; 3 - rotary modulus at the fixation angle within 0° to 90°; 4- the device for moving the gripping device (Double-acting pneumatic cylinder of the brand DSNU-12-200-P-A of the company "FESTO"); 5 - four-finger gripping device.

4.3 Study of the functional characteristics of the mechatronic module of the gripping device

At the first stage, the functional characteristics of the mechatronic module of the gripping device were studied, in relation to the reproduction of the contour of the generator surface of the gripping object by the working surface of the fingers. The place of contact of the surface of the fingers with the object and the ability of the fingers to provide additional fixation of the object by bending their limbs at the ends of the object were investigated. The results of the research are presented in fig. 4.5 - fig. 4.11.

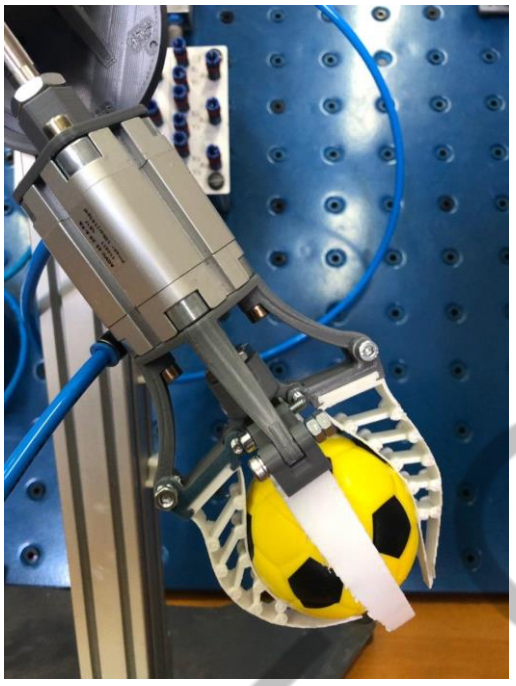
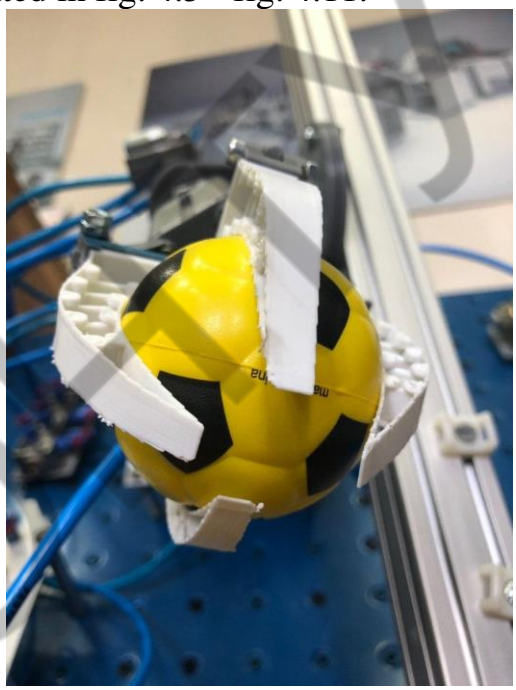
a)  b) 

Fig. 4.5. Study of gripping round artificial objects: a - the working surface of the fingers takes the shape of the object; b - additional fixation of the object by bending the ends of the fingers on the ends of the object

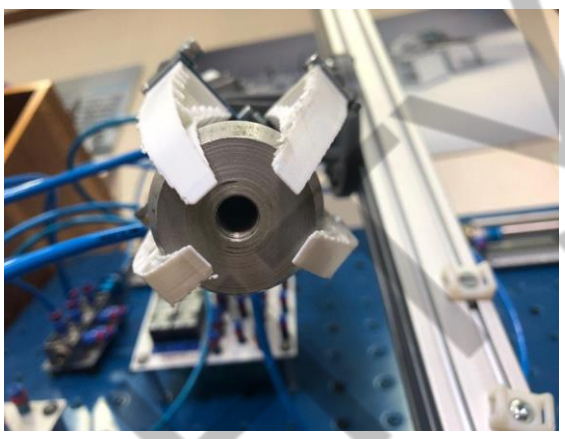
a)  b) 

Fig. 4.6. Study of gripping of artificial objects of cylindrical shape: a - the working surface of the fingers takes the shape of the object; b - additional fixation of the object by bending the ends of the fingers on the ends of the object.

a)  b) 

Fig. 4.7. Study of gripping artificial objects of complex shape: a - the working surface of the fingers takes the shape of the object; b - additional fixation of the object by bending the extremities of the fingers.

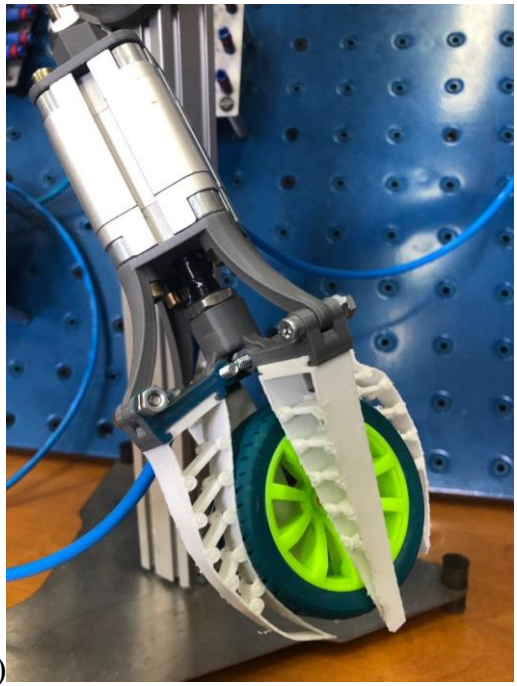
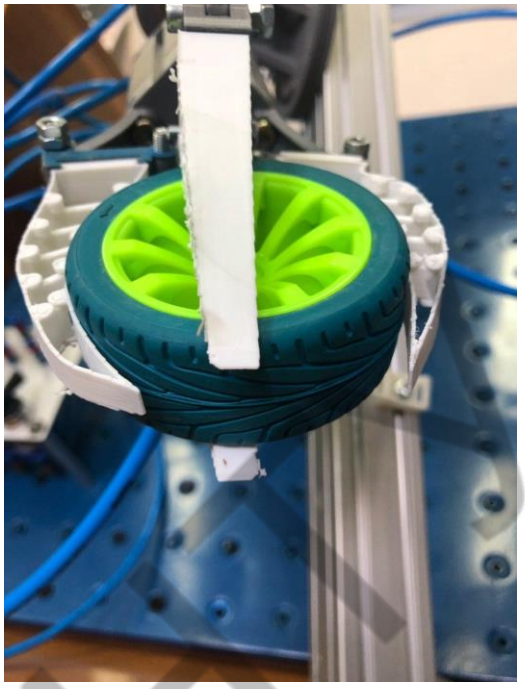
a)  b) 

Fig. 4.8. Study of gripping artificial objects of cylindrical shape: a - the working surface of the fingers takes the shape of the object; b - additional fixation of the object by bending the ends of the fingers on the ends of the object.

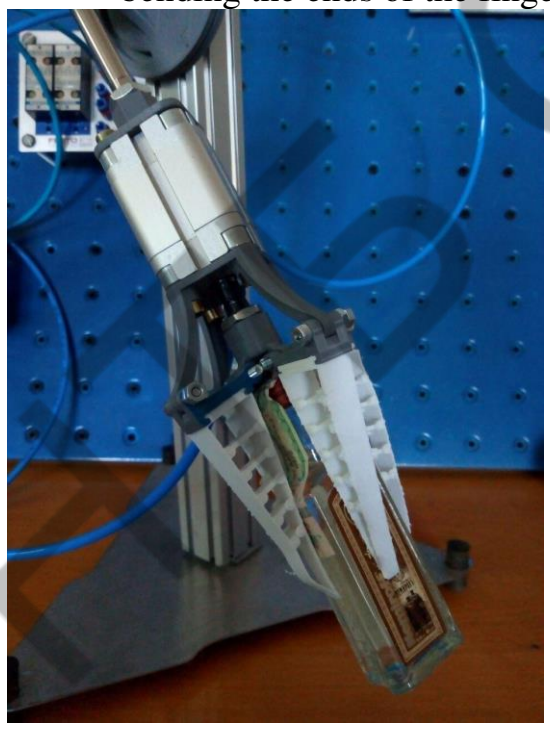
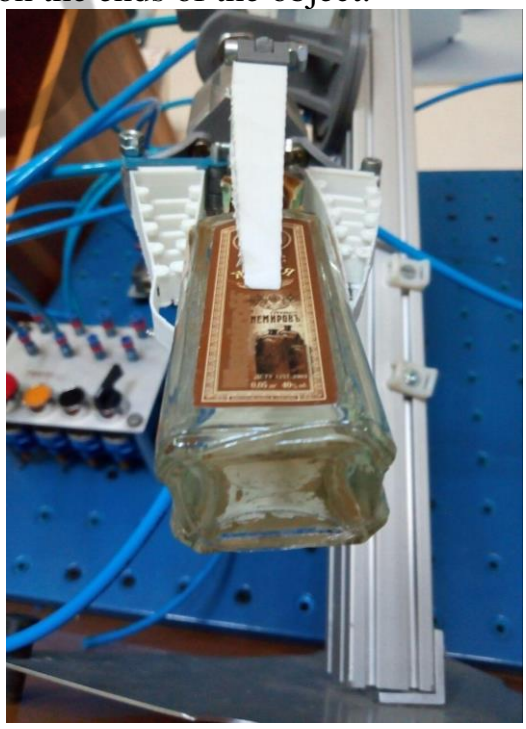
a)  b) 

Fig. 4.9. Study of gripping artificial objects of rectangular shape: a - the working surface of the fingers takes the shape of the object; b- additional fixation of the object by bending the ends of the fingers on the ends of the object.

a)  b) 

Fig. 4.10. Study of gripping of artificial objects of complex shape on the inner surface of their body: a - the working surface of the fingers takes the shape of the object; b - additional fixation of the object by bending the ends of the fingers along the inner wall of the object.

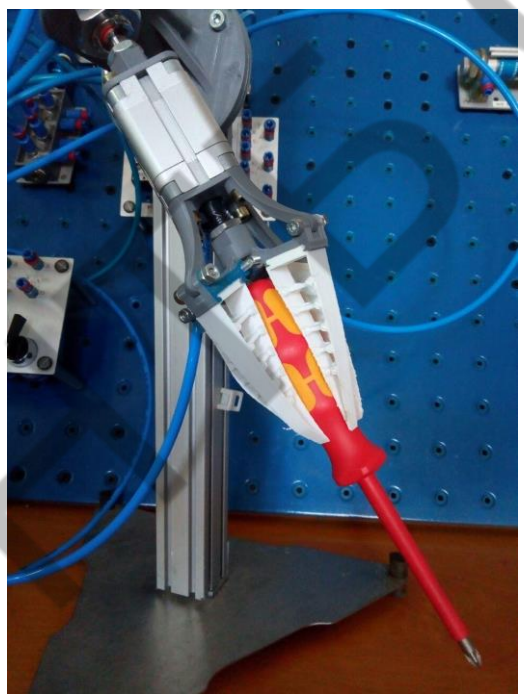
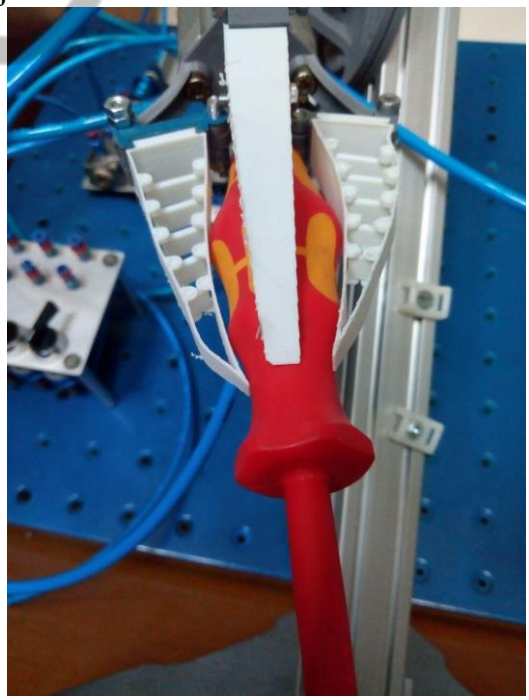
a)  b) 

Fig. 4.11. Study of gripping artificial objects of complex shape:
a - the working surface of the fingers takes the shape of the object; b- additional fixation of the object by bending the extremities of the fingers.

4.4 Study of the durability of the elements of the gripping device on the basis of bionics

At the second stage, the durability and quality of the structural elements of the gripping device were investigated. The prepared drawing of the fingers was created using Autodesk Inventor software and manufactured on a 3D printer from various materials (Fig. 4.12).

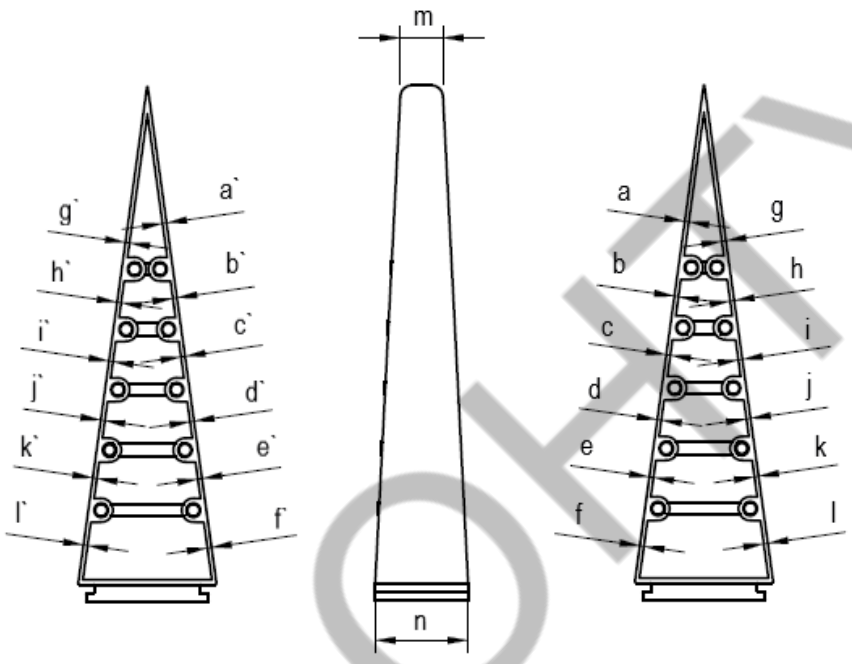


Fig. 4.12. Scheme of the gripping finger with selected areas of measurement of the structure working surfaces in section (a -1) and height (m)

It is common knowledge that inexpensive three-dimensional printing technologies are known for some inaccuracies in production [16]. In most cases, there are defects in filling the material of products and problems with printing thin walls. Therefore, after printing the models, the fingers were checked for size compliance. To do this, the thicknesses of individual sections of the structures working surface in places of the most possible destruction during cyclic loading and the height k were measured (Fig. 4.12).

To obtain a more accurate result, 5 attempts were made for each measurement, from which the maximum and minimum sizes were set and the average size obtained from them. On the basis of conducted measurements, the structural locations that have the largest spread of dimensions m were determined. It was established that such discrepancies are caused by shrinkage of the processed material from which the component is made (Fig. 4.13).

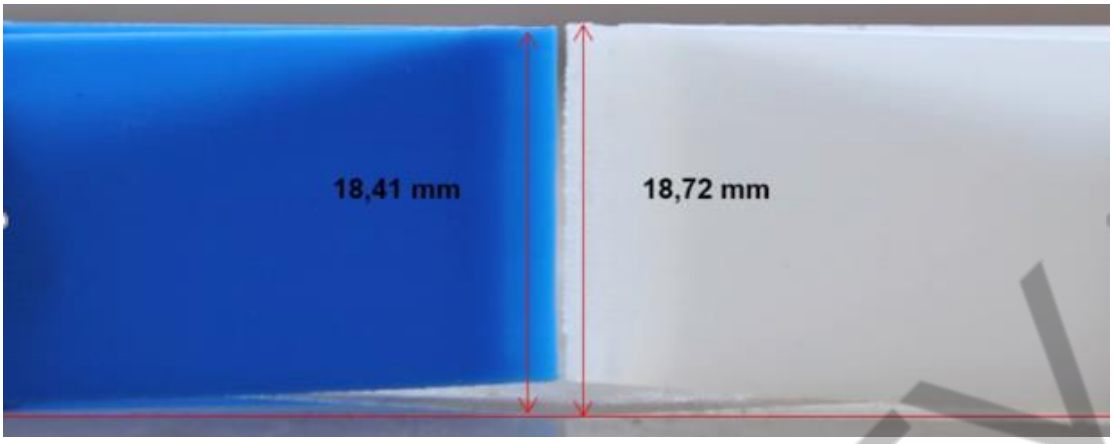


Fig. 4.13. The results of measuring the width of the gripping devices working surface of made of different materials

The next stage of the research was the fatigue test of the obtained finger structures (Fig. 4.14).

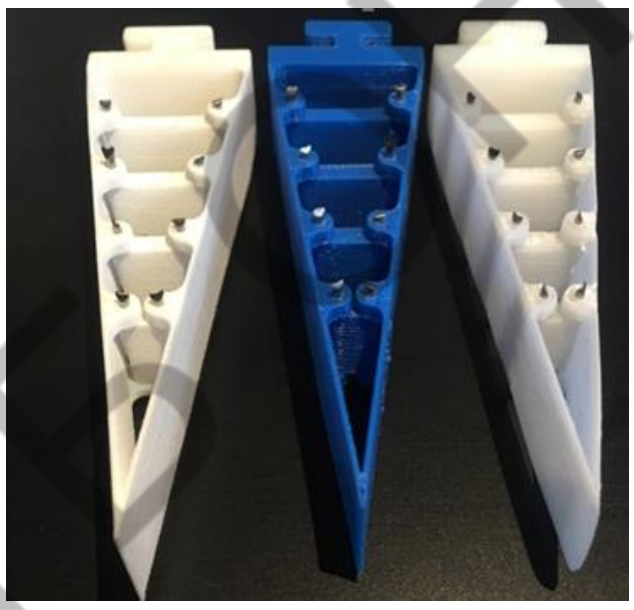


Fig. 4.14. Designs of fingers from different materials

For this purpose, the experimental setup was programmed in the automatic mode of operation with cyclic operation of the fingers by gripping. The amplitude and frequency of the deflection of the fingers working surfaces was up to 10 mm and 2 Hz, respectively. It was established that the fingers of the gripping device, which are made of ABS (acrylonitrile-butadiene-styrene) material, were destroyed in the area of application of the maximum mandrel load (Fig. 4.15). The place of destruction of a finger made of such material coincides with the results of analytical studies of structural elements According to the research results, the safety factor for the ABS material was calculated, which is about 1.39.

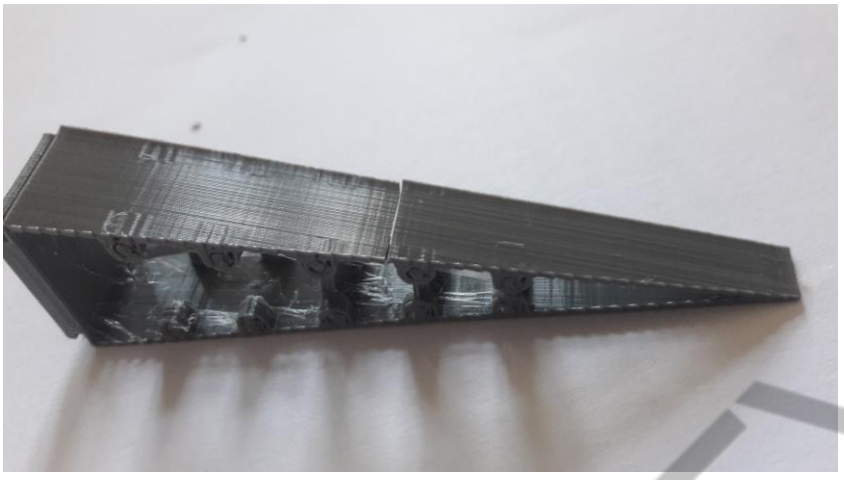


Fig. 4.15. Type and location of failure of a finger made of ABS material after a fatigue test

It was investigated that the gripping fingers made of PLA material (polylactic acid) were destroyed at the base - in the place of attachment to the bar (Fig. 4.16). Based on the results of research, the estimated safety factor for the material - PLA is about 1.68.

Fig. 4.16. Type and location of failure of a finger made of PLA material after a fatigue testing

It was established that the grip rods made of Elastan material (Polyethylene terephthalate) were destroyed in the place where the stiffeners were connected. (fig. 4.17). Based on the results of research, the safety factor for this material - Elastan, which is about 1.18, was calculated.

Fig.4.17. Type and location of failure of a finger made of Elastan material after fatigue testing

According to the results of experimental tests, the dependence of the number of cycles of the gripping finger before destruction was determined as a function of the force applied by the finger to the object. The obtained results are presented in the form of a graph for fingers made of materials: ABS . PLA and Elastan (Fig. 4.18).

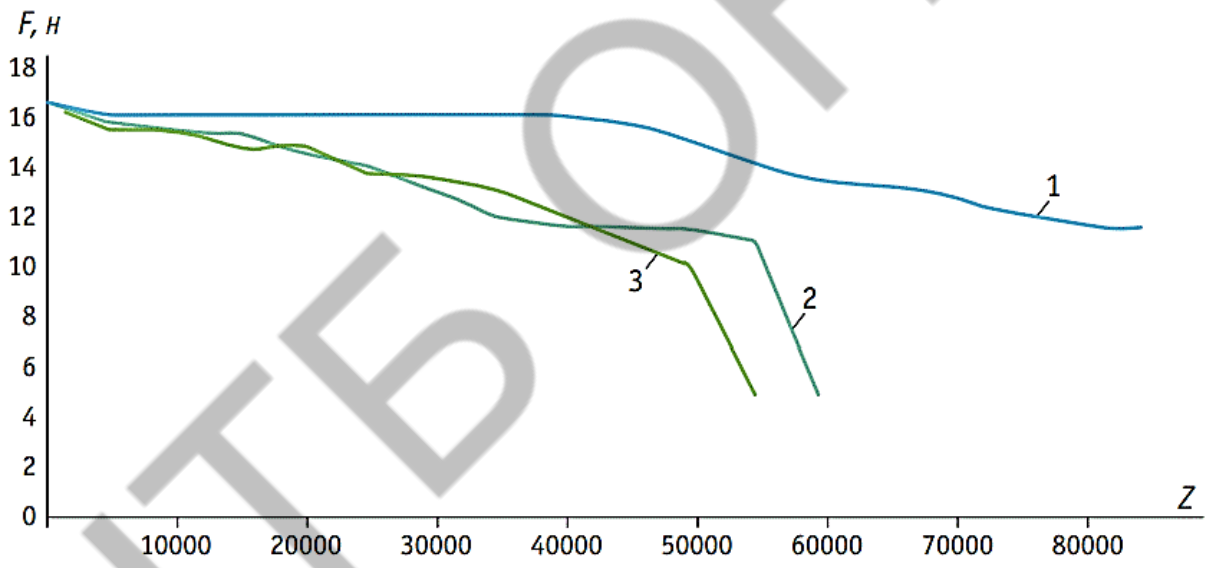


Fig. 4.18. Results of experimental research on the number of work cycles of the gripping finger to destruction as a function of the force applied by the finger to the object for materials: 1- PLA; 2- ABS; 3- Elastane

V. CONCLUSIONS

According to the research of modern gripping devices:

- It has been established that the philosophy of creating a new generation of gripping devices for group packaging is based on the principles of bionics. It is the methods of gripping objects by living organisms - animals and humans that have led to the

appearance of innovative designs of gripping devices adapted for the packaging industry.

- A new design of the mechatronic module of the gripping device based on bionics with enhanced functionality for performing group packaging operations is proposed.
- Technical documentation has been developed for the production of a mechatronic module of a gripping device based on bionics with enhanced functionality for performing group packaging operations.
- An experimental installation of a mechatronic module of a gripper device based on bionics was developed and manufactured.
- It has been studied that finger samples made of ABS flex material can work stably up to 55,000 cycles, characterized by a change in force from 16.5 N to 12N. In subsequent cycles, the load rapidly changes from 12N to 4N. The destruction of the sample occurs around 60,000 cycles.
- It has been studied that samples made of PLA material are characterized by the greatest functional capabilities. The printed finger showed the possibility of stable operation up to 80,000 cycles. Its further use leads to a slow decrease in stiffness and load. The destruction of the sample occurs around 200,0000 cycles.
- It has been studied that finger elements made of Elastan material (polyethylene terephthalate) are characterized by functional capabilities of stable operation up to 40,000 cycles. Its further use is characterized by only a slight effort, which leads to the destruction of the stiffness elements around 55,000 cycles.
- The stress change analysis made on the 3D CAD model in Autodesk Fusion allowed to determine the zones of maximum stress changes on the elements of the gripping finger during its operation. The location of the failure of the samples made of PLA and ABS materials coincided with the most probable zones of maximum stress in the Autodesk Fusion 360 software.

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ANALYSIS OF COLOR NOISE EFFECT ON QUALITY OF RECOVERING THE CHAOTIC SIGNALS

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Recently, during the development of the modern information transmission systems, more and more attention has been paid to the search for new ways of forming and processing signals, which can simultaneously ensure the necessary level of stealth and speed of information transmission. Chaotic signals with OFDM modulation satisfy these requirements. However, the effectiveness of their functioning has investigated only during impact of the "white" noise. Nonetheless, in real radio communication channels there are other types of noise, which called color noise. Such noises occur due to interference in the environment of propagation of radio signals and in the signal generation tools.

In article has been analyzed the influence on chaotic signals with OFDM-modulation noises of different colors. The noises have generated by lineal integral transformation of "white" noise with Mandelbrot's kernel. The obtained results showed that if in received signal presence the useful signal and one type of color noise ("white", "pink", "black") the required level of message recovery is achieved with approximately equal signal/noise ratios. The number of subcarriers in chaotic signal with OFDM-modulation influence on the quality of recovering, their increase leads to the increase the required signal to noise ratios on the receiver side.

However, during the presence in received signal additive mixture of useful signal, "white" and "color" noise the necessary level of recovery the binary message can be obtained during the signal to "white" noise ratio more than 18 dB, and signal to "color" noise ratio should be not less than 16 dB. The obtained results have showed the necessary of development methods to increase the quality of recovery chaotic signals with OFDM-modulation under the influence of colored noises.

Keywords: *the information transmission system, color noises, OFDM, signal-to-noise ratio, probability of correct estimation.*

I. INTRODUCTION

Today, the electronic means that ensure the control of troops and forces provide a potential opportunity for the enemy to reveal our combat capabilities, actions and intentions, as well as to prevent our use of these means by destroying them or by radio suppression. Taking into account the high-speed development of enemy electronic warfare means, there is a need to develop and introduce new types of signals capable of providing the necessary level of electronic protection of our communications. [1-2]. This can be achieved by ensuring a high level of secrecy of the signals used in information transmission systems, since in this case the enemy will not be able to detect, determine the type and reveal the information transmitted by the radio signal [3-6]. One of the possible ways to form signals with a high level of secrecy is to use chaotic processes and

sequences whose properties are close to the properties of "white" noise. As signs of chaotic signals, the topology of the set of signal points in pseudophase space is used. [7]. As a numerical measure of the proximity of chaotic signals to "white" noise (Independent and Identically Distributed (IID)-stealth) use non-parametric Brock Dechert Scheinkman (BDS)-statistics [3-7].

However, when using chaotic signals in real communication channels, the question arises as to the effectiveness of their recovery on the receiving side, especially given that they are influenced not only by "white", but also by color noise. The paper considers the problem of assessing the quality of recovery of chaotic signals with OFDM-modulation with analytical chaotic signals during exposure to color noise.

II. ANALYTICAL REVIEW OF THE LITERATURE

2.1. General information about signals with OFDM-modulation

Currently, active work is underway around the world to introduce and expand the areas of application of wireless data transmission, radio communications, radio broadcasting and television, based on signals with OFDM-modulation. Developed in the 60s of the last century, signals with OFDM-modulation due to the imperfection of the then technologies became available for use only relatively recently [8]. It was first used about 40 years ago in several military systems: KINEPLEX, ANDEFT and KATHRYN. Thus, the KINEPLEX TE-206 data transmission system provided transmission at a speed of 2400 bit/s using 8 channels (sub-carriers), and TE-202 – 3000 bit/s using 40 channels. In this case, the frequency spread between the subterfuges was not less than or equal to $\Omega = 2\pi / T$ (T – length of the clock interval), because with mutually incoherent sub-carriers it is impossible to ensure their orthogonality with less peddling [9].

As areas of application of signals with OFDM-modulation can be identified [9]:

– in the standards of digital terrestrial broadcasting: DVB-T, DVB-T2, DVB-H, DVB-SH, DVB-T2lite, T-DMB, ISDB-T, MediaFLO, Eureca-147, DAB, DAB+, DRM, DRM+;

– in wired communication channels used in the standard of cable digital television broadcasting DVB-C2 and data transmission ADSL, VDSL;

– for data transmission over a power line based on the PLC standard;

– in data transmission standards IEEE 802.11a/g/n/ac, IEEE 802.16d/e, IEEE 802.16m, LTE, LTE-A and future 5G generation networks;

– in ultra-wideband data networks based on the IEEE 802.15.3a standard (Ultra-Wideband Technology, UWB) and its subsequent developments;

– in satellite and radio relay communication systems;

Signals with OFDM-modulation were widely used in military radio communication systems of the power structures of the world. NATO ground forces have developed communication systems using the military version of the IEEE 802.11g standard. by MobiComm. Nova Engineering offers serial communication systems for the US Navy (HDRLOS Radio Modem), which implement the principle of OFDM. The wide

distribution of OFDM was facilitated by the choice of this signal modulation technology as the physical basis for the creation of tactical broadband networks (Wideband Networking Waveform WNW) within the framework of the Joint Tactical Radio System (JTRS) program. In the long-term plan for the development of unmanned aircraft systems of the United States, it was noted [10] that WNW is planned to be used as radio communication lines with an unmanned aerial vehicle (UAV) based on WiBro technology (Wireless Broadband, IEEE 802.16).

The principle of operation of signals with OFDM-modulation is that the available frequency band is divided between the set of subcarrier frequencies. In addition, each subsurface can be modulated using different types of digital modulation (BPSK, QPSK, QAM). Thus, in the time domain, a complex signal with OFDM modulation can be written as follows. [8]:

$$S_k = S(k\Delta t) = \frac{1}{N}\sum_{n=0}^{N-1} \dot{U}_n e^{jnk\frac{2\pi}{N}} \qquad (1.1)$$

where N is the number of subcarriers; $k = 0,1,2,3...(N\text{-}1)$ – Discrete time; Δt – Sampling period; $\dot{U}_n$ – complex information symbol [5-8].

As a result of the use of signals with OFDM-modulation, all characters are transmitted simultaneously while the duration of each character effectively increases N times compared to the sequential transmission of characters at the same frequency.

In case of frequency separation of subcarriers, it is necessary that on the one hand the width of each is narrow enough to minimize the curvature of the signal within its limits, and on the other wide enough to ensure the required speed of information transmission. In addition, for the economical use of the entire bandwidth of the channel, divided into subcarriers, it is necessary to place them as close as possible near each other, while avoiding interchannel interference to ensure complete independence of the subcarriers from each other. In signals with OFDM-modulation, this is realized using orthogonal frequency sub-carriers, that is, the condition is met:

$$\int_0^T \sin 2\pi f_l(t) \sin 2\pi f_k(t) dt = 0, k \neq 1 \qquad (1.2)$$

where T is the duration of the symbol; f_l and f_k – the frequencies of the l-th and k-th subcarriers, respectively.

Orthogonality between subcarriers is ensured only when, during the duration of one symbol T, the carrier signal will perform an integer number of oscillations. Since each symbol of duration T is transmitted by a time-limited sinusoidal function, its spectrum is described by a function of the type:

$$\frac{\sin 2\pi(f - f_i)}{2\pi(f - f_i)} \tag{1.3}$$

where f_i is the central (carrier) frequency of the i-th channel. The same function describes the shape of the subchannel.

The spectra of the subcarriers overlap with each other without interference, as shown in Figure 1. 4. Orthogonality allows on the receiving side to select each subcarrier from the total number, despite the partial overlap of their spectra. Due to this, a high spectral efficiency of the modulated OFDM signal is achieved. [9-11].

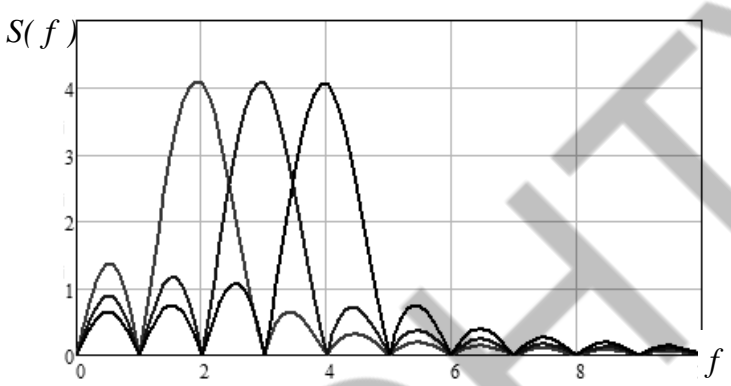


Fig. 1.1 – Spectrum of the subcarriers signal with OFDM-modulation

The implementation of a system with signals with OFDM-modulation, which consists of generators in the transmitter and a set of matching filters in the receiver, is quite difficult for a large number of subcarriers. Therefore, for the rapid implementation of signals with OFDM-modulation using computing devices, the algorithm of direct and inverse fast Fourier transform (FFT) is used. With the help of an inverse FFT in the transmitter, the sum of the subcarriers obtained as a result of modulation is "collapsed" into one, which is converted into a digital form and transmitted to the communication line. Further, on the receiving side, the conversion from a digital form to an analog one occurs, a direct FFT is performed, after which the subcarriers are demodulate into one sequence.

Signals with OFDM modulation are used by many wireless and wired communication standards due to the following advantages:

1. Resistance to narrowband interference. When using signals at one carrier frequency, fading or interference can lead to loss of information, at the same time a small amount of information will be damaged in signals with many subcarriers.

2. Resistance to frequency-selective fading, due to parallel transmission (each sub-carriers has a narrow frequency band relative to the total width of the signal band).

3. High spectral efficiency, which ensures the orthogonality of the subcarriers among themselves.

4. The use of multi-position types of modulation to increase the speed of data transmission.

However, the disadvantages of using signals with OFDM modulation include:

1. During the appearance of the Doppler effect in a signal with OFDM modulation, a change in the central carrier frequency occurs, which leads to a change in the entire spectrum of the useful signal, which in turn leads to a violation of the orthogonality of the subcarrier frequencies.

2. High peak factor value (8 ... 12 dB).

3. The protective interval used in signals with OFDM modulation to combat multi-beam propagation reduces the spectral efficiency of the signal.

4. Low level of secrecy of such signals during their use in secure information transmission systems [12].

2.2. The principle of constructing chaotic signals with OFDM-modulation

In most modern radio engineering transmission systems, harmonic oscillations are used as an information carrier [11-14]. The information signal in the transmitter modulates these oscillations by amplitude, frequency or phase, and in the receiver information is released through the reverse operation – demodulation. Modulation of the carrier can be carried out, either by modulating already formed harmonic oscillations, or by controlling the parameters of the generator in the process of oscillation formation.[14].

However, the need to resist the means of unauthorized access to information puts forward increased requirements for solving the problem of ensuring its protection, which information transmission systems with harmonic signals cannot provide. Therefore, in [3-6] it is proposed to use dynamic (deterministic) chaos. The main feature that distinguishes it from ordinary noise is that it is implemented using a specific mathematical algorithm, which allows you to reproduce it on the receiving side. Modulation of chaotic signals by information can be carried out in the same way as for harmonic ones. However, the possibilities here are much wider. Indeed, if in the case of harmonic signals of controlled characteristics – only three (amplitude, phase and frequency), then in the case of chaotic oscillations, even a small change in the control parameter gives a reliably fixed change in the nature of the oscillations [15]. Chaos generators with changing parameters have a wide range of schemes for entering an information signal into a chaotic one (that is, modulating a chaotic signal with an informational one). In addition, interest in chaotic signals is related to the fact that that they are broadband, that is, they have a greater information capacity. In communication systems, a wide frequency band of carrier signals is used both to increase the transmission rate and to increase the stability of the systems in conditions of interference [15]. This property of chaotic processes is most often used to encode information [4-7].

Recently, broadband methods of chaotic modulation have been in the spotlight. They consist in modulating information bits by chaotic implementations, which are obtained through appropriate chaotic reflections. Chaotic implementations have broadband and non-periodicity properties and a pulsed autocorrelation function. Typically, systems with chaotic modulation are divided into coherent, for which it is necessary to have a copy of the original chaotic implementation in the receiver, and incoherent, in which the signal detection process does not require such a copy. To evaluate

discrete reflections from the point of view of ensuring secrecy when using them as models of chaotic oscillation generators, we will further use the following indicators: autocorrelation function, energy spectrum and degree of homogeneity of "image" points in pseudophase space. It is important that the values of the control parameters of the imaging are those that would provide an autocorrelation function with a narrow peak and low lateral emissions, a uniform and broadband energy spectrum in the frequency band, and the proximity of the "image" in pseudophase space to the "image" of "white" noise [16].

Taking into account the possibilities of chaotic reflections to provide the necessary level of secrecy of information transmission systems in the work [17], a method of forming sub-carriers for chaotic signals with OFDM-modulation using one-dimensional chaotic reflection of Chebyshev's polynomials of the 1st kind of the 3rd order was proposed and investigated (Fig. 1. 2):

$$x_{n+1} = 4x_n^3 - 3x_n, \qquad (1.4)$$

where $n = 1 \ldots N$ – the number of samples in the sequence; x_0 – the initial value of the sequence.

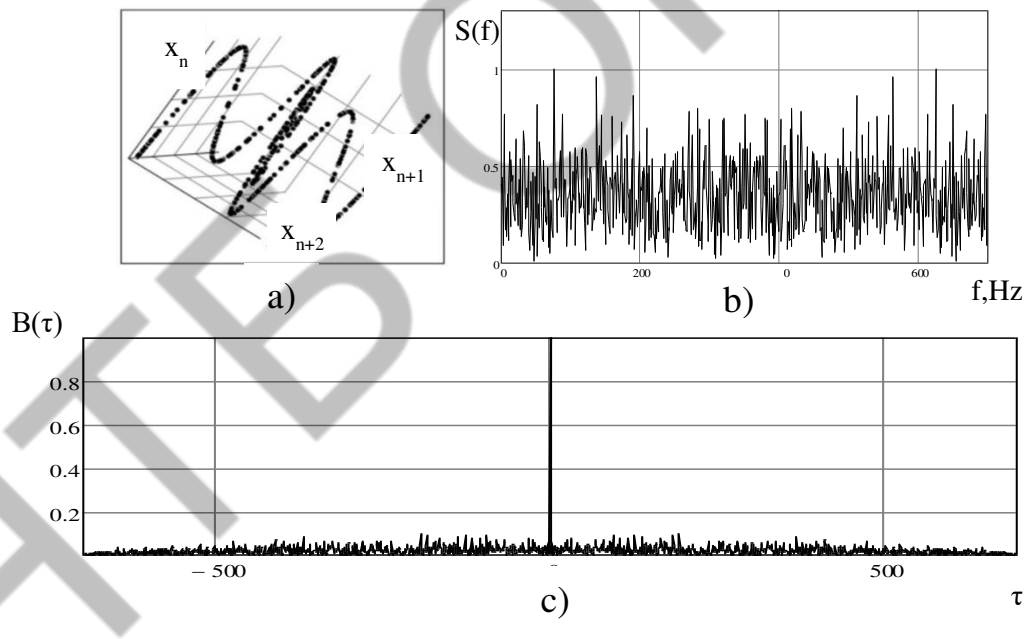


Fig. 1. 2 – Reflection of the Chebyshev polynomial 1 of the kind 3 order: a) "image" in pseudophase space; b) the energy spectrum; c) autocorrelation function

It is known [4-7] that the disadvantage of using such reflections is the structure of their "images" in pseudophase space, which significantly distinguishes them from random processes. Therefore, to complicate the structure of the "image" and change the statistical characteristics of the input chaotic sequence, the authors [17] used the concept of an analytical signal [3]. On a set of discrete values, an analytical signal was obtained in a

complex form, according to the expression $\dot{x}_n = x_n + jy_n$, where $y_n = \{y_0, y_1, \ldots y_{N-1}\}$: the imaginary part of the analytical signal is given by the Hilbert transformation to the input sequence $x_n = \{x_0, x_1, \ldots x_{N-1}\}$. The application of the Hilbert transform provides amplitude $A_n = \sqrt{x_n^2 + y_n^2}$ and phase $\psi_n = \arctan\left(\frac{x_n}{y_n}\right)$ signal [3]. After transferring the complex amplitude to the harmonic frequency of modulation, an analytical chaotic sequence (ACS) was obtained in the form of $s_n = \mathrm{Re}(A_n e^{j\omega n}) = A_n \cos(\psi_n + \omega n)$. Further, to organize the secretive transfer of information, elements of the "1" information sequence $\{r_v\}_{v=1}^{V}$ (r is 0,1 were transmitted with frequency in ACS ω_1, and elements "0" with ω_2, according to:

$$s_n = \begin{cases} A_n \cos(\psi_n + \omega_1 n), & r = 1, \\ A_n \cos(\psi_n + \omega_2 n), & r = 0. \end{cases} \qquad (1.5)$$

During the transition from a discrete chaotic signal to its continuous representation in a given frequency band in the range from 0 to some upper limit frequency $f_в = F$ the method of interpolation of Shannon – Kotelnikov was used [5]. It has been suggested that the expression (1.5) is a narrowband process that is fully determined by the sequence of its instantaneous values $\{s_n = s(nT_0), n = 0, \pm 1, \ldots, \pm N - 1\}$, the distance between which is equal to the interval $T_0 \le 1/2F$. Then, after transferring the received signal to the carrier frequency, the chaotic signal with OFDM-modulation (OFDM-ACS) can be recorded:

$$s(t) = \sum_a \left(\sum_n s_{a,n} \gamma_n \cos\left(2\pi f_a \left(T_0 t - n\right)\right) \right), \qquad (1.6)$$

where $\gamma_n(t) = \mathrm{sinc}(T_0 t - n)$; $f_a = aF$, $f_1 = 2F$, $a = 1 \ldots A$ – numbers of transmitted chaotic sub-carriers.

However, the authors [17] investigated the quality of message recovery formed using chaotic signals with OFDM-modulation (1. 6) only when exposed to "white" noise. However, when receiving signals against the background of noise, the use of the "white" Gaussian process model is not always advisable, since in it all frequencies affect the signal equally [18]. While, for example, the use of "brown" (Brownian) noise has a greater effect on low frequencies, and "black" on high frequencies. Therefore, for a more complete analysis of the effectiveness of the functioning of ITS with chaotic OFDM-ACS signals, it is necessary to investigate the effect of fractal (color) Gaussian noise on them. In [19] the authors made an assessment of the effect of color noise on radio communication

channels. The statistical and spectral properties of noise were analyzed and it was shown that color noises are always present in the received radio signals along with the "white" noise. To assess the presence of color noise components in the adopted implementation, the Leung-Box statistical test was used, which tests the null hypothesis that the accepted time series is "white" noise. Calculations of the probability of correct message recovery for wireless communication channels showed that the presence of an additive mixture of color and "white" noise significantly reduces the reception quality. This indicates the need to take into account such noise when modeling real communication channels.

The paper [20] describes the dispersion estimation algorithm, which refutes that the resulting process is "white" noise. As real signals, sub-carriers of signals with OFDM-modulation were chosen. The obtained algorithm takes into account the real radio signal propagation medium, where noise is not characterized by constant spectral power. This situation often occurs when exposed to severe interference. The intensity of color noise in the signal is detected by calculating the autocorrelation of the spectral power density. At the same time, when noise is not colored, the proposed algorithm works in the same way as traditional calculators of the dispersion of "white" noise.

Below we will consider the problem of assessing the probability of correct recovery of a message from chaotic OFDM-ACS signals against the background of "white" and color noise.

III. OBJECT, SUBJECT AND METHODS OF RESEARCH

The object of study - random, chaotic and regular processes in radio engineering systems of information transmission.

The subject of the study - the study of the influence on chaotic signals with OFDM-modulation of color noise by methods of the statistical theory of information-measuring systems.

Research methods. During the solution of the tasks, modern methods of digital signal processing, classical and non-traditional mathematical statistics, methods of nonlinear dynamics, methods of the statistical theory of observation processing, simulation and statistical modeling in the Mathcad application package were used.

IV. WORK RESULTS

Let us investigate the effect of colored noise on the signals formed according to (1.6). To model colored noises, we will use the linear integral transformation of "white" noise with the Mandelbrot kernel and its discrete approximations, which generalize Brownian motion and allow us to obtain a set of random processes with different fractal dimensions [7]:

$$\Delta B_H(t) \approx \frac{n^{-\frac{1}{2}}}{\Gamma\left(H+\frac{1}{2}\right)}\left[\left[\sum_{i=0}^{[n\cdot(t+1)]-1}\left((t+1)-\frac{i}{n}\right)^{H-\frac{1}{2}}\eta_i\right]-\left[\sum_{i=0}^{tn-1}\left(t-\frac{i}{n}\right)^{H-\frac{1}{2}}\eta_i\right]\right] \quad (1.7)$$

or

$$\Delta B_H(t) \approx \frac{n^{-\frac{1}{2}}}{\Gamma\left(H+\frac{1}{2}\right)}\left[\left[\sum_{i=nt}^{[n\cdot(t+1+M)]-1}\left((t+1+M)-\frac{i}{n}\right)^{H-\frac{1}{2}}\eta_i\right]-\left[\sum_{i=nt}^{n(t+M)-1}\left(t+M-\frac{i}{n}\right)^{H-\frac{1}{2}}\eta_i\right]\right] \quad (1.8)$$

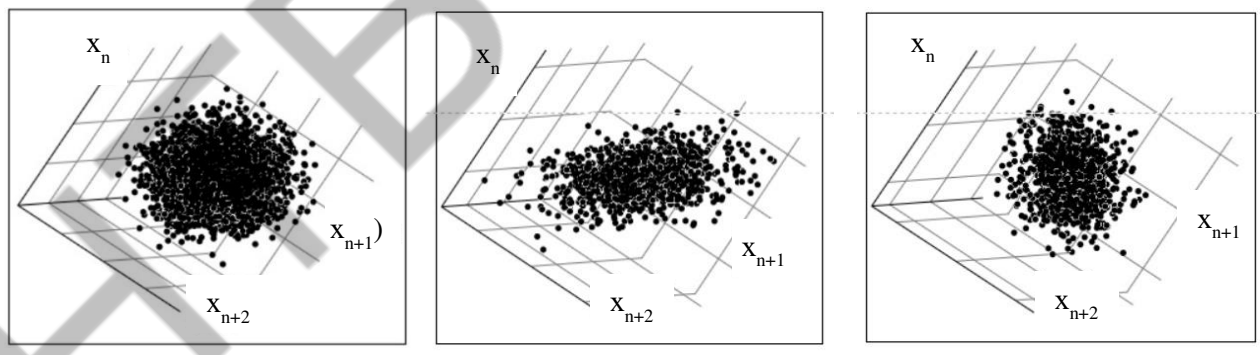
where $\{\eta_i\}$ – "white" noise with zero mean and unit variance with $i = 1, 2, ..., M, ...$;

n – a kernel parameter that sets the final capacity;

M – filter order;

H – the Hurst index (coefficient of self-similarity), which takes values from the interval [0, 1].

Expressions (1.7) and (1.8) are equivalent to calculating the average value from "white" noise for positive values of time with a power-law weight function that has no features for the values. Expression (4) allows using a fixed number of elements of the generation process, which is equivalent to calculating a moving average in a window with *nM* integer steps. Depending on the value of the Hurst indicator in (1. 8) it is possible to get different types of color noise. "Images" of processes in pseudophase space at different values of the Hurst indicator are shown in Fig. 1. 3.



a) b) c)

Fig. 1.3 "Shapes" of processes in the pseudo-phase space at the values of Hurst exponent: a) – $H = 0.5$ ("white" noise); b) – $0.5 < H < 0.9$ ("black" noise); c) – $0 < H < 0.5$ ("pink" noise).

From Fig. 1.3 shows that at $0 < H < 0.5$, the points on the "image" in the pseudophase space are grouped along the diagonal with a negative derivative. This

indicates a decrease in dependence in the data and antipersistence is observed ("pink" noise), that is, if the values of the process increase in the previous period of time, it is most likely that they will fall in the next period, and vice versa. Independent and equally distributed values formed in the Mandelbrot kernel, when $H = 0.5$. On the interval $0.5 < H < 0.9$ (fig. 1c) a rotation of the "shape" in the pseudo-phase space of the transformed process has observed in the direction of the diagonal with a positive derivative. It indicates an increase in the dependence between the values of the modeling process and its desire for persistence ("black" noise). The property of persistence indicates the desire to preserve the trend in the evolution of the process. A persistent process has a long-term memory, which manifested in an increase in the horizon of predictability of the process and strong correlations between its values, which lag far behind each other. Table 1.1 shows the types of color noise depending on the value of the Hurst coefficient H in (1.8).

Table. 1.1 – The property of persistence indicates the desire to preserve the trend in the evolution of the process. A persistent process has a long-term memory, which manifested in an increase in the horizon of predictability of the process and strong correlations between its values, which lag far behind each other. Table 1.1 shows the types of color noise depending on the value of the Hurst coefficient H in

Color of noise	**The value of the Hurst coefficient, *H***
"brown"	H~0.1
"pink"	H~0.3
"white"	$0.4 \le H \ge 0.6$
"grey"	$0.6 < H \ge 0.7$
"black"	$H > 0.7$

It has to be noted that on receiver enters an additive mixture of the useful signal and noise. Therefore, processing of such signal must carry out using known methods of the statistical theory of radio engineering systems. For this purpose, after receiving the signal and dividing it into subcarriers, it is possible to perform correlation processing of the received signal [21]. To determine the frequency in ACS, at which "0" or "1" transmitted, the input signal in the duration interval of one symbol multiplied by a set of ACS with different frequencies $\left\{\omega_i = i\Delta_\omega\right\}_{i=1}^{100}$, that change with the step $\Delta_\omega = 0.01$. Afterward, the frequency in the ACS determined based on the maximum response and accepted one of the two hypotheses: H_0 – a message element with an ACS frequency ω_0, or H_1 – a message element with an ACS frequency ω_1.

It is important to investigate the probability of correct message recovery depending on the SNR q at the receiver input. The probability of correct message recovery and SNR determinate according to [21]:

$$P_{rec}(q) = k(q)/K, \tag{1.9}$$

where k – the number of realizations in which the condition of correct recovery effect for SNR q;

K – total number of tests.

and

$$q = 10\lg\left(\sigma_s^2 / \sigma_n^2\right), \tag{1.10}$$

where σ_s – power spectral density of the useful signal;

σ_n – power spectral density of the noise.

Figure 1.4 shown the simulation data of the binary message elements discrimination using correlation processing of the input signal against the background of colored noise with different values of the Hurst index in (3.2) (*H=0.3, H=0.5, H=0.9*). The total number of tests equal *K = 1000*.

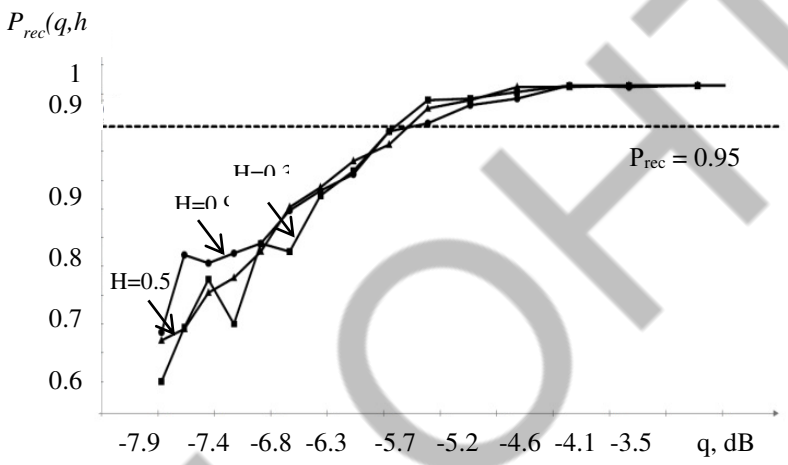


Fig. 1.4 – The probability of correct message recovery depending on the value of the Hurst's index in the chaotic signal with OFDM-modulation.

The analysis of the obtained results shows that the color of the noise has a slight effect on the probability of correct message recovery of a chaotic signal with OFDM-modulation. At the value of the SNR *q=-5dB*, the largest P_{rec} obtained against the background of "pink" noise, while for "white" and "black" noises it 0.01 lower.

However, it necessary to give an empirical estimate of the probability of correct message recovery $P_{rec}(q,h)$ depending on the number of subcarriers *h* in the signal with OFDM- modulation (3.9) and the SNR. By noise mean the presence of "white" noise (*H=0.5*), "pink" (*H=0.3*) and "black" noise (*H=0.9*). Figure 1.5 shows the $P_{rec}(q,h)$ values for 4 and 8 subcarriers in signal with OFDM-modulation depending on the SNR of color noise. The total number of tests equal *K=1000*.

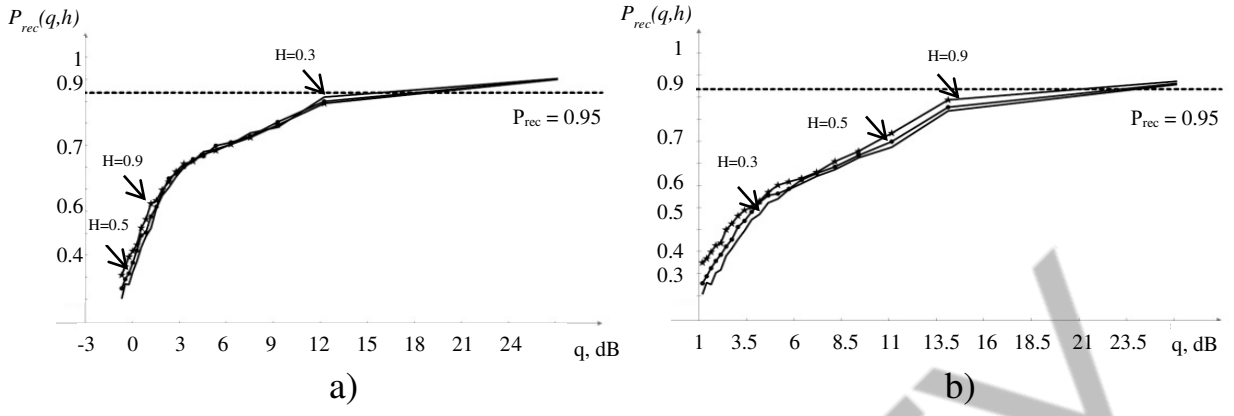


Fig. 1.5 The probability of correct message recovery depending on the noise color and the number of subcarriers in chaotic signal with OFDM-modulation: a) h=4; b) h=8.

The analysis of the figure 1.5 indicates that with an increase in the number of subcarriers *h* in signal with OFDM-modulation, the required level of probability of correct message recovery $P_{rec} \geq 0.95$ provided at higher SNR. At *h=4*, the SNR should be *q≥18 dB*, and at *h=8*, *q≥23 dB*. It means that an increase the number of subcarriers increases *q* by *5 dB.* Also, it can be concluded that the color of the noise does not make significant additional changes in the probability of correct message recovery. However, it should be noted that at the input of receiver observed an additive mixture of the useful signal and noise, which can be represented by the sum of "white" and colored noises. Therefore, Figure 1.6 shows the curves of probability of correct message recovery of chaotic signal with OFDM-modulation on *h=8* subcarriers when in the input signal presence the sum of "white" and "pink" noises and of "white" and "black" noises. The total number of tests equal *K=1000*. The power spectral density of color noise equal to σ_n=1.

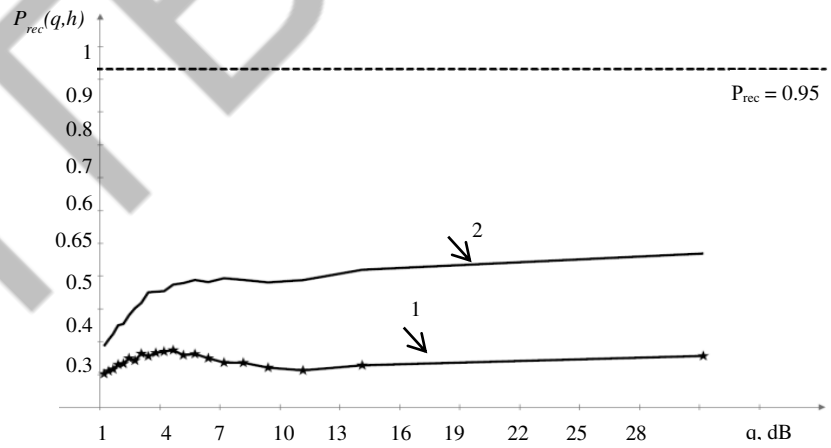


Fig. 1.6 – The probability of correct message recovery of a chaotic signal with OFDM-modulation on h=8 subcarriers when in the input signal presence the sum of "white" and "pink" noises (1) and of "white" and "black" noises (2).

The analysis of the obtained dependencies (Fig. 4) indicates that the presence of an additive mixture of the useful signal, "white" and color noise in the receiver input leads to a significant deterioration of the reception quality, in which the required level of $P_{rec} \geq 0.95$ not provided at all. Moreover, the additive mixture of "white" and "pink" noise has the greatest negative impact on chaotic signals with OFDM-ACS-modulation. For a more detailed study of the outflow of color noise to chaotic OFDM-ACS signals, it is necessary to investigate the probability of correct recovery of the message from such signals during a change in the power of the signal/color noise ratio and the constant value of "white" noise. For this Fig. 1.7 shows the probability curves of correct recovery of the message from chaotic OFDM-ACS signals to 8 subcarriers depending on the power of "black" and "pink" noise and the signal/noise ratio q = 18 dB, q = 11 dB, q = -1 dB.

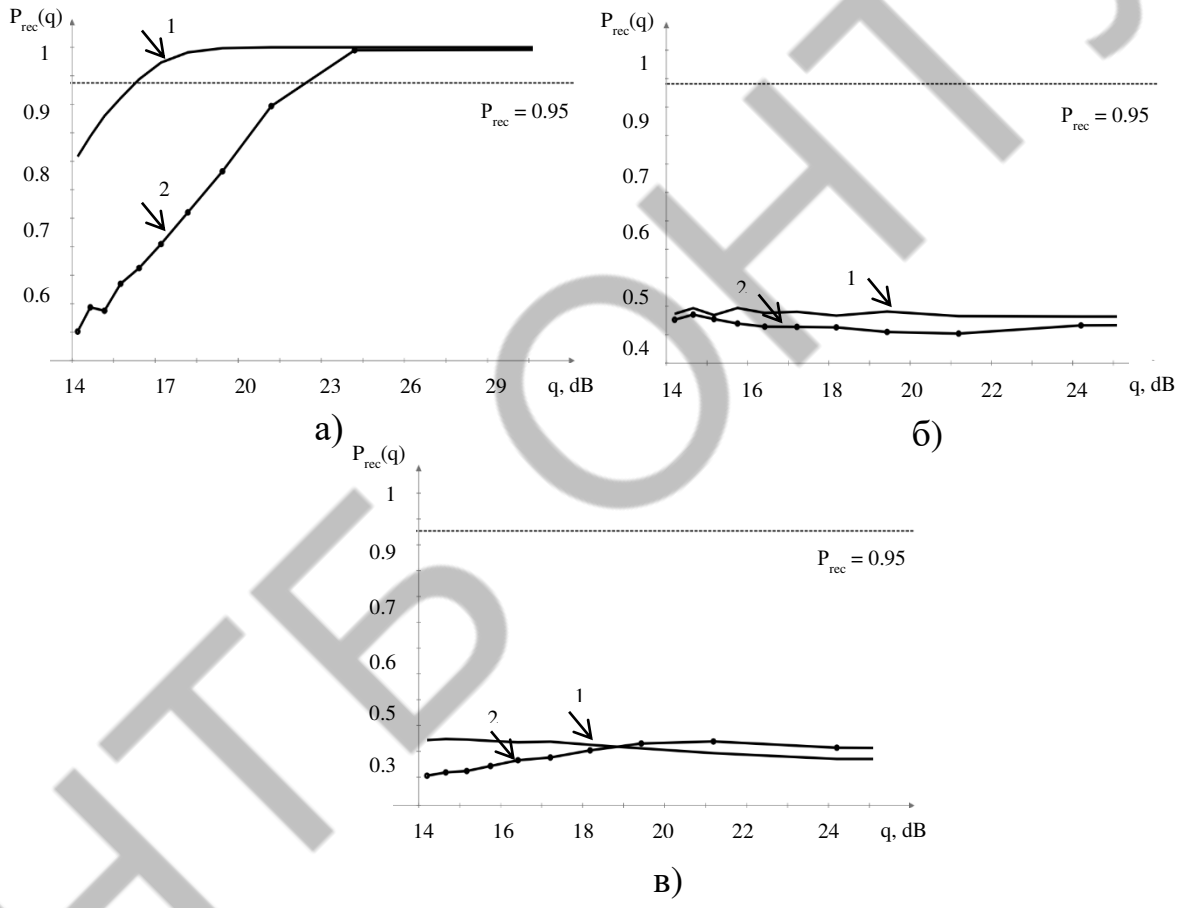


Fig. 1.7 – The probability graph of the correct recovery of the message from the chaotic signal OFDM-ACS to 8 subcarriers, depending on the power of the "pink" noise (1) and "black" noise (2) at a constant value of the signal/"white" noise ratio: a) q = 18 dB; b) q = 11 dB; c) q = -1 dB

Analysis of the obtained curves (Fig. 1.7) indicates that in order to effectively recover a message from chaotic OFDM-ACS signals during exposure to color noise, the signal/"white" noise ratio at the input of the receiving device must be q ≥ 18dB. In this case, the required level of recovery of the message $P_{rec} = 0.95$ is provided during the

power of the "black" noise of 22 dB, while for the "pink" it is 6 dB less and equal to 16 dB. This indicates that the most negative impact on the chaotic signal OFDM-ACS has the presence of "black" noise in the radio communication channel.

To explain the results obtained, we construct the spectral power density in the frequency region of various noises and the generated signal (Fig. 1. 8) and their autocorrelation functions (Fig. 1. 9).

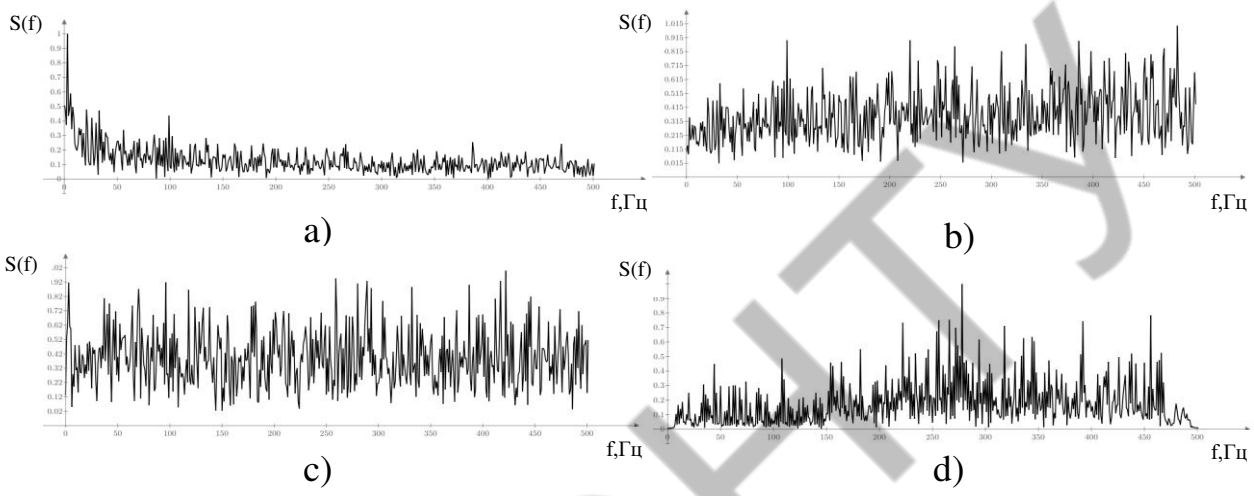


Fig. 1. 8 – Spectral power density in the frequency region of noise: a) "black"; b) "pink"; c) "white"; d) OFDM-ACS for 8 subcarriers

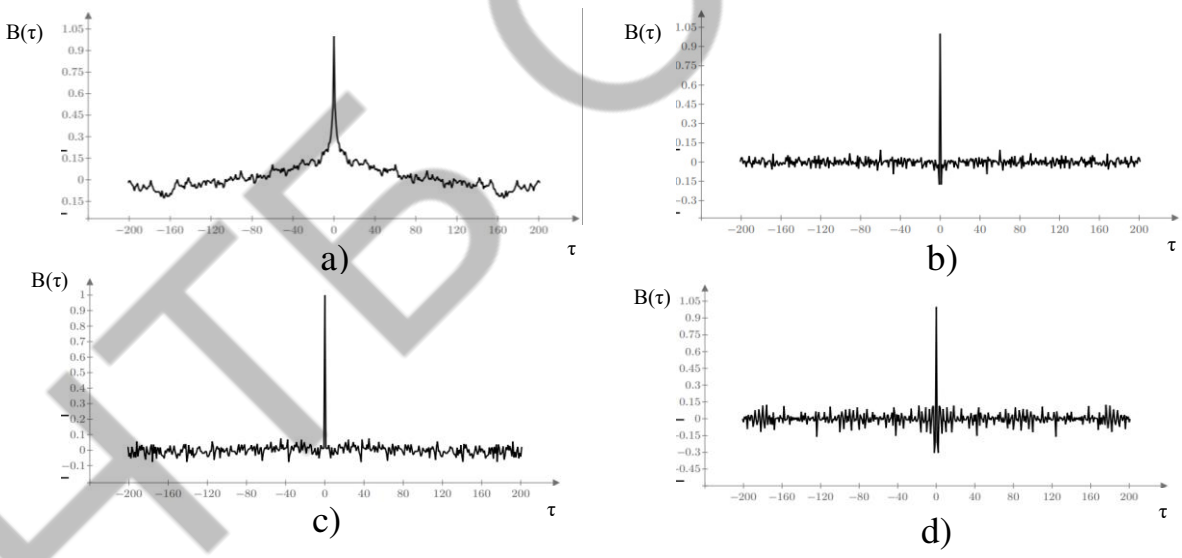


Fig. 1. 9 – Autocorrelation functions of noise: a) "black"; b) "pink"; c) "white"; d) OFDM-ACS for 8 subcarriers

The presence in the accepted implementation of only "white" noise (Fig. 1. 8c, 1. 9c) does not introduce significant distortions in the signal, since the spectral power density of such noise is constant at all frequencies, and the correlation intervals are close to zero. In this case, the correlation receiver is able to restore the message at lower signal-to-noise ratios. However, when adding a mixture of "white" and "pink" noise to the accepted

implementation (Fig. 1. 8b, 1. 9b) the quality of recovery is reduced. This is explained by the fact that in the "pink" noise the correlation intervals between the values increase, and the spectral power density focuses on low frequencies. This all makes the process more correlated and increases the necessary signal-to-noise ratios to correctly restore the message in the correlator. However, the most negative effect on the quality of message recovery is the presence of a mixture of "white" and "black" noise (Fig. 1. 8a, 1. 9a), since in the "black" noise there are the largest correlation intervals, and the spectral power density is concentrated at high frequencies.

Thus, the proposed method of forming chaotic signals OFDM-ACS makes it possible to provide the necessary level of IID and structural secrecy of hidden information transmission systems. At the same time, in order to effectively restore such signals on the receiving side, the signal-to-noise ratio must be q ≥ 18 dB.

V.CONCLUSIONS

The work investigated the effect on chaotic signals with OFDM-modulation of noise of different colors. The noises were generated using a linear integral "white" noise conversion with the Mandelbrot core. The obtained results show that when there is a useful signal and one type of color noise ("white", "pink", "black") in the accepted implementation, the required level of message recovery is achieved approximately at equal signal/noise ratios. The quality of recovery is affected by the number of subcarriers in a chaotic signal with OFDM-modulation, their increase leads to an increase in the required signal/noise ratios at the receiver input.

However, during the presence in the adopted implementation of an additive mixture of the useful signal, "white" and color noise, the necessary level of restoration of the binary message $P_{rec} \geq 0.95$ can be provided during the ratio signal/"white" noise at the input of the receiving device $q \geq 18dB$, and the level of the ratio signal/color noise should not be less than 16 dB. The obtained results indicate the need to develop methods for improving the quality of restoration of chaotic signals with OFDM modulation under the influence of colored noise.

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A NETWORK OF HOTSPOTS FOR POINTS OF INVINCIBILITY

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***Abstract* —** *The topic of this work is the realization of a network of hotspots. This work provides basic information about wireless communication technology (Wi-Fi) and its advantages, which ensure the rapid spread of hotspots across Points of Invincibility in Ukraine. A study of hotspots network of Points of Invincibility was carried out on the example of the Primorsky district of the city of Odessa to provide the use of Internet resources to citizens and internally displaced persons.*

***Keywords* —** *Hotspot, wireless network, Point of Invincibility, Starlink internet-terminal, peak hour.*

I.INTRODUCTION

In connection with the large-scale power outage in Ukraine due to russian shelling of the energy infrastructure in the country, the Points of Invincibility, which were previously announced by the President of Ukraine Volodymyr Zelenskyi, began to be opened. Thus, over 4,000 such points have been prepared throughout the country. The plan of the terrorism sponsor country is to leave the residents of Ukraine without electricity, light and heat. In the event of a long-term emergency power outage, Points of Invincibility become an island of safety, stability, and warmth, which operate around the clock and are free for temporary stay [1].

Now it is planned to equip Points of Invincibility with Starlink internet-terminals, but there are not enough of them [2]. Services to be provided in the Points of Invincibility, despite the power outage consists of:

Fig.1. Services at Points of Invincibility

II. LITERATURE ANALYSIS

The majority of such points are organized and equipped using the allocated resources of executive authorities and local self-regulation agencies in each territorial area. As for the

Points of Invincibility organized by responsible businesses (operating at the expense of the business), they provide an opportunity to warm up and recharge mobile devices. Other services may be at charge at the discretion of the owners. Currently, there are about 150 Points of Invincibility in Odessa, but only 55 of them provide Internet access [1].

The study examines twelve Points of Invincibility from the point of view of providing the possibility to get free Internet access in the city of Odesa. Points of Invincibility in Odesa are characterized by a large influx of citizens, guests of the city and internally displaced persons. All of them are in a great need of fast and high-quality communication with relatives and employees at working enterprises. In addition, in the central part of the city there is an opportunity to connect network equipment to the packet transport network.

Therefore, the topic of introducing a network of hotspots operating on the wireless Wi-Fi radio access protocol (Wireless Fidelity) in Points of Invincibility, is relevant to this day. According to the National Commission for State Regulation in the Field of Communication and Informatization, the state of the telecommunications services market for 2021 in Ukraine, excluding the temporarily occupied territory of the Autonomous Republic of Crimea, the city of Sevastopol, and part of the temporarily occupied territories in the Donetsk and Luhansk regions, covers services of mobile communication, fixed access to the Internet, fixed telephone communication services, provision of infrastructure facility channels, etc.

The main indicators of the industry for 2021 are as follows: the total annual revenue of the communications market amounted to UAH 81 billion, 91% of which is traditionally revenue from the provision of telecommunication services. In the structure of revenues from the provision of telecommunication services in 2021, the largest share was mobile communication - 66% and fixed Internet access - 19.5%. There is a noticeable increase in revenues from the provision of mobile communication services, which in 2021 increased by 14% compared to 2020 [3]. Below is an infographic of the state of telecommunications services in Ukraine. The state of the telecommunications services market according to the data of the annual report for 2021, received as of March 20, 2022, is presented in Fig. 2. The mass use of modern communication services using LTE technologies, which became possible after the launch of 4G networks in 2018 by the three largest telecommunications operators, gave a tangible impetus to increase a demand for the usage of mobile Internet by Ukrainians. In 2021, revenues from the provision of Internet access services increased by 14% compared to last year.

During 2021, mobile operators significantly expanded coverage on the territory of Ukraine with 4G networks, which made it possible to increase the share of the population that can receive mobile broadband access to the Internet, which significantly speeds up and facilitates all personal and business interactions. Behind the scenes, constant work on improving the quality of services and building networks continues. The ideology of the Internet network, which was initially developed at the initiative of the US Department of Defense in case of nuclear war, has now become an increasingly pervasive ideology on which the majority of information systems designed for widespread use are built.

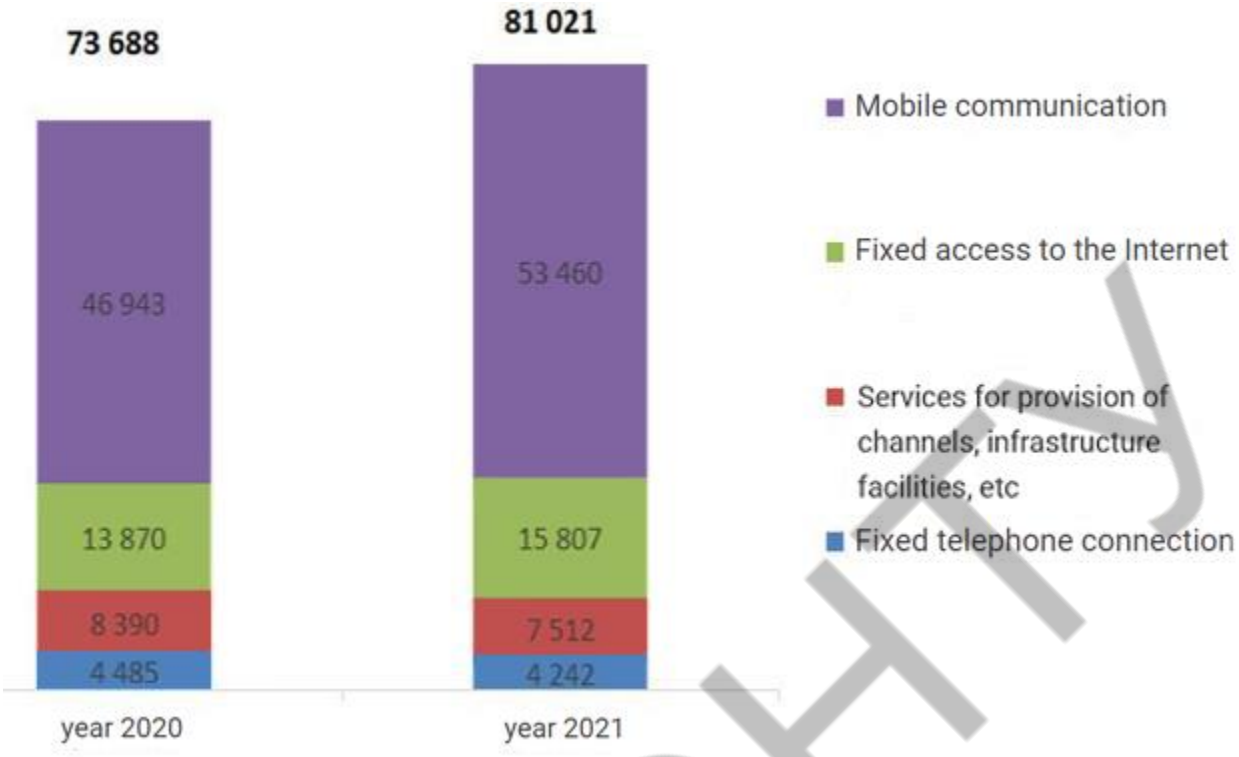

Fig. 2. Structure of revenues of telecommunication services, million UAH.

Today, the Internet unites many different networks, millions of computers, hundreds of millions of users from all continents, and according to various estimates, the number of such users increases by 50-80% annually. The Internet provides prompt access to information on any topic [4].

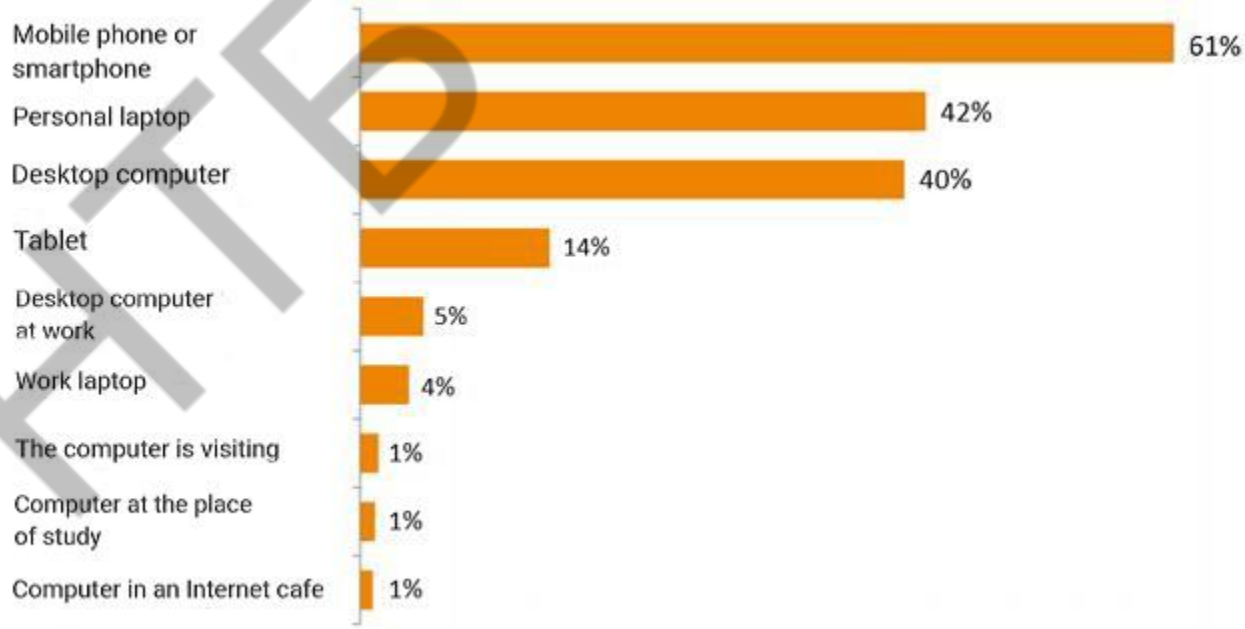

Fig. 3. Distribution by types of access of regular users to the Internet in Ukraine (according to Factum Group Ukraine) [5].

Mobile devices (pocket computers, smartphones and laptops) equipped with client Wi-Fi adapters can connect to the local network and access the Internet through access points - Hotspots.

This technology has a number of advantages that ensure its rapid spread. It allows you to deploy networks without laying cables, which reduces the cost of creating and expanding networks.

Places where it is not possible to lay a cable, for example, outside the premises of buildings of historical value, can be served by Wi-Fi networks. In addition, Wi-Fi devices are widely distributed on the market, and devices from different manufacturers can interact at the basic level of services. It is easy to add new equipment to a wireless network, which is a disadvantage of cable networks.

Wi-Fi is a set of global standards. Unlike mobile phones, Wi-Fi equipment can work in different countries around the world.

The availability of standards that provide different data transfer speeds allow you to choose the most optimal equipment to ensure the necessary functionality of the selected services.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The total number of subscribers with high-speed Internet access is constantly growing. The largest share is made up of subscribers who get access to the Internet through wireless communication channels - 66%. Thus, the use of Wi-Fi technology for the rapid organization of high-speed access networks is expedient and economically beneficial.

The object of this topic regarding the introduction of hotspots network in Points of Invincibility is the study of the literature on Wi-Fi radio access technology, the creation of a scheme of the network of hotspots, the calculation of network segment indicators.

The subject of the study is a network of hotspots for public access to the Internet in Points of Invincibility.

Research methods - analysis of Wi-Fi technologies, comparative analysis of Wi-Fi radio access network equipment, application of software for modeling network segment indicators.

Wi-Fi technology is most effective for building wireless local networks (WLAN) and for organizing so-called active zones (Hotspots) - access points in places where potential users are concentrated, who have terminals with Wi-Fi support (portable and pocket personal computers with appropriate hardware modules). Such points can be deployed in places of public catering, the client base of which consists of representatives of small and medium-sized businesses and wealthy sections of the population; in hotels, waiting rooms of airports, railway and bus stations.

The cycle of organizing wireless public Wi-Fi networks consists of the following stages:

1) creation of a project of the future Wi-Fi zone;
2) equipment selection and configuration;
3) organization of a local wireless network;

4) access settings and Internet connection
5) protection against unauthorized access.

The radio access network of Wi-Fi technologies is deployed quickly and with relatively low costs, due to the use of a significant amount of standard local area Ethernet network hardware. Access points (AP) are used on the network, which will provide access to the public data transmission network and a large number of subscriber stations. The access points provide interaction over the radio channel with subscriber stations through the radio interface of the 802.11 standard, and through the Ethernet protocol they interact with the public data transmission network. Access points and base stations (BS) have standard Ethernet interfaces. 10/100/1000BASE-T LAN port. Each access point provides coverage of the service area. The radius of the service area depends on the parameters of the physical level and depends on the generated load.

Access points of one active with the help of an Ethernet switch interact with each other, as well as with service servers.

Since the main use for the Wi-Fi network (IEEE 802.11 standard) is mass access to the Internet, lines with a significant capacity of Gigabit Ethernet are appropriate in the area of access to the transport network.

The MCE Y.1231 recommendation provides the following elements of a Wi-Fi access network (IEEE 802.11 standard):

1) SESM (Subscriber Edge Services Manager) server for managing services on the subscriber side for registering users and visitors to the network, which allows you to distinguish your own users of the radio access network from users of other networks that currently use this network, and charge them accordingly for the services provided.
2) the main and backup AAA servers (Authorization, Authentication, Accounting) for user authentication, access authorization and billing, the information and functions of which are duplicated; user authentication is possible using the common RADIUS protocol;

When organizing an active Wi-Fi zone, payment for the provided services should be organized by prepaid cards for mass Internet access. Hotels, public catering outlets etc. should have a possibility to receive a single bill for the services of the main activity together with telecommunication services received through the radio access network.

For the Wi-Fi hotspot, support for virtual local area networks (VLAN) is expected to ensure greater network security.

The following protocols SNMP, Telnet, SSH and WEB can be used to centralize maintenance and control of the Wi-Fi network.

Designing a Wi-Fi network (IEEE 802.11 standard) should include the following stages:

1) Planning of the nomenclature of multi-service services and the main parameters of subscriber radio access - load and required bandwidth of information transmission.
2) Determination of potential zones of concentration of radio subscribers and initial planning of capacities and placement of BS from the point of view of optimal coverage of the given territory.

3) Choosing the physical topology of the radio access network, calculating its load and the required transmission speed, specifying the required number of BSs in the case of a cellular topology, and designing their connection to the packet transport network.
To build a Wi-Fi broadband network (IEEE802.11 standard), you need to choose a certain type of equipment. Among the most common manufacturers of wireless equipment, we can highlight: Cisco and D-link.

Cisco is a world leader in the field of network technologies. Unlike many other technology companies, Cisco does not make a firm choice in favor of one technology. The Cisco company discloses its solutions in the field of modern technologies, which include:
1) IP communications;
2) network security;
3) wireless LANs;
4) storage networks (SAN);
5) home networks;
6) video systems;
7) applied network services.

At the moment, the leader in the production of wireless equipment is the D-Link company. The company produces a new family of wireless devices that provide, due to a number of innovations (according to the specification), a high speed of data transmission.

Access points of D-Link equipment are chosen for the deployment of the hotspot network in the city of Odesa, namely: wireless dual-band unified AC2600 access points with Power over Ethernet (PoE) support that meet European and Ukrainian standards (Fig. 4).

Fig. 4. Wireless dual-band unified access points AC2600 DWL 8620AP [6].

The external wireless dual-band access point D-Link AC2600 is an ideal solution for creating hotspot zones that provide Internet access to users located on outside of the premises. The AC2600 provides a reliable wireless connection at a speed of up to 300 Mbps in the 2.4 GHz frequency band and up to 866 Mbps in the 5 GHz band. Thanks to this feature, as well as support for the Wi-Fi Multimedia ™ (WMM) Quality of Service (QoS) function, the access point is an ideal solution for transmitting audio, video and voice

applications. The included QoS function allows the AC2600 access point to automatically prioritize network traffic according to the level of interactive streaming, such as HD video or VoIP. The QoS feature can be adjusted through the AC2600 access point's web interface using a drop-down menu to select user-defined priority rules. In addition, the AC2600 supports load balancing to ensure maximum performance by limiting the number of users per access point. Thanks to the support of the 802.11ac wireless standard and powerful antennas, the access point can be placed almost anywhere convenient for the user, where it is necessary to organize a wireless network coverage area.

AC2600 allows network administrators to create a controlled and reliable wireless network with optimal coverage both in the 2.4 GHz frequency range (802.11b, 802.11g and 802.11n) and in the 5 GHz range (802.11a, 802.11n and 802.11ac). The AC2600 access point supports the 802.3af Power over Ethernet standard, which allows you to install this device in places where power outlets are not available.

Network administrators have several options for managing AC2600 access points, including a Web interface (HTTP), Secure Socket Layer (SSL, which provides a secure connection to the Web interface), Secure Shell (SSH, which provides a secure channel between the access point and remote computer) and Telnet.

For advanced network management, administrators can use D-Link Central Wi-Fi Manager, which allows you to configure and manage multiple access points from one computer. In addition to standard management options, D-Link Central Wi-Fi Manager allows network administrators to remotely check equipment, eliminating the need for personal control of any operations.

Consider the technical characteristics of the Cisco Catalyst 3750 series router. Cisco Catalyst 3750 series switches are stack multi-level switching devices designed for a Gigabit Ethernet network with performance of 10/100/1000 Mbit/s. The switches are intended for medium-level corporations and branches of large companies [7].

They are distinguished by ease of use and the highest fault tolerance among stack switches. For this project, we choose Cisco Catalyst WS-C3750-24FS-S.

The switches are managed via the web interface over a network connection or via the command line interface with the use of console port or Telnet network. The software has three execution options:

1) IP Base Image - advanced quality of service (QOS), traffic management, access control lists (ACL), multicast filtering (IGMP Snooping), static and dynamic routing based on RIP and EIGRP.

2) IP Service Image - extended set of 3rd level functions: multicast traffic routing, policy-based routing, extended set of routing protocols.

3) Advanced IP Service Image - IPv6 routing and advanced IP services.

The physical topology of the radio access network is determined by the potential zones of concentration of radio subscribers, their number and location in the Points of Invincibility.

Therefore, the installation of access points is considered from two points of view - optimal coverage of the given territory and places of concentration of potential users. The

designed network will have a loop topology, which is an alternative topology for deploying wireless broadband radio access networks.

This topology is the most effective for a wireless network, because the load between the nearest users can be closed using wireless means, and the access point will be accessed through the terminal of one of these users. Such a radio access network consists of the following levels: the level of users, at which load exchange is ensured between them; external access level at which users access the transport network. The "loop" topology provides high efficiency in the use of network resources and allows you to quickly increase its bandwidth and change its configuration imperceptibly for subscribers.

The radio access network, subject to the scalability of the IEEE 802.11a/b/g/n/ac standard, the so-called active zone (hot spot) of Wi-Fi technology in the city of Odesa, is formed on the basis of twelve access points located in the Points of Invincibility of Odesa.

An uninterruptible power supply (UPS) is installed for each radio access point in case of failures in the external power grid.

Three active zones are considered for the designed network, all access points of one active zone are connected to each other and to service servers using Ethernet hubs. All three load concentrators of active zones are connected by a switch in order to connect to the transport network through a telephone exchange.

In the area of access to the transport network, lines with a significant capacity of Gigabit Ethernet are used. The main and backup AAA servers and the SESM server located in the premises of the city automatic telephone exchange (ATE) are installed for the network.

For the Wi-Fi hotspot, support for virtual local area networks (VLAN) is expected to ensure greater network security.

The following protocols SNMP, Telnet, SSH, and WEB can be used to centralize maintenance and manage the wireless network.

Features of wireless network planning:

1) the location of access points depends on the required coverage area and building construction;

2) thick walls, or walls with metal structures, will block the signal more strongly. It is desirable to reduce the number of walls and partitions to a minimum - each wall can reduce the maximum data transmission distance to 30 or more meters;

3) office furniture, offices, can form "shadows" in the coverage area;

4) direct visibility is necessary to obtain a larger coverage area;

5) place wireless devices away (at least 1-2 meters) from electrical devices that can generate a radio signal.

Fig. 5 shows a plan-map with the topology of the network of hotspots in Points of Invincibility in Odesa.

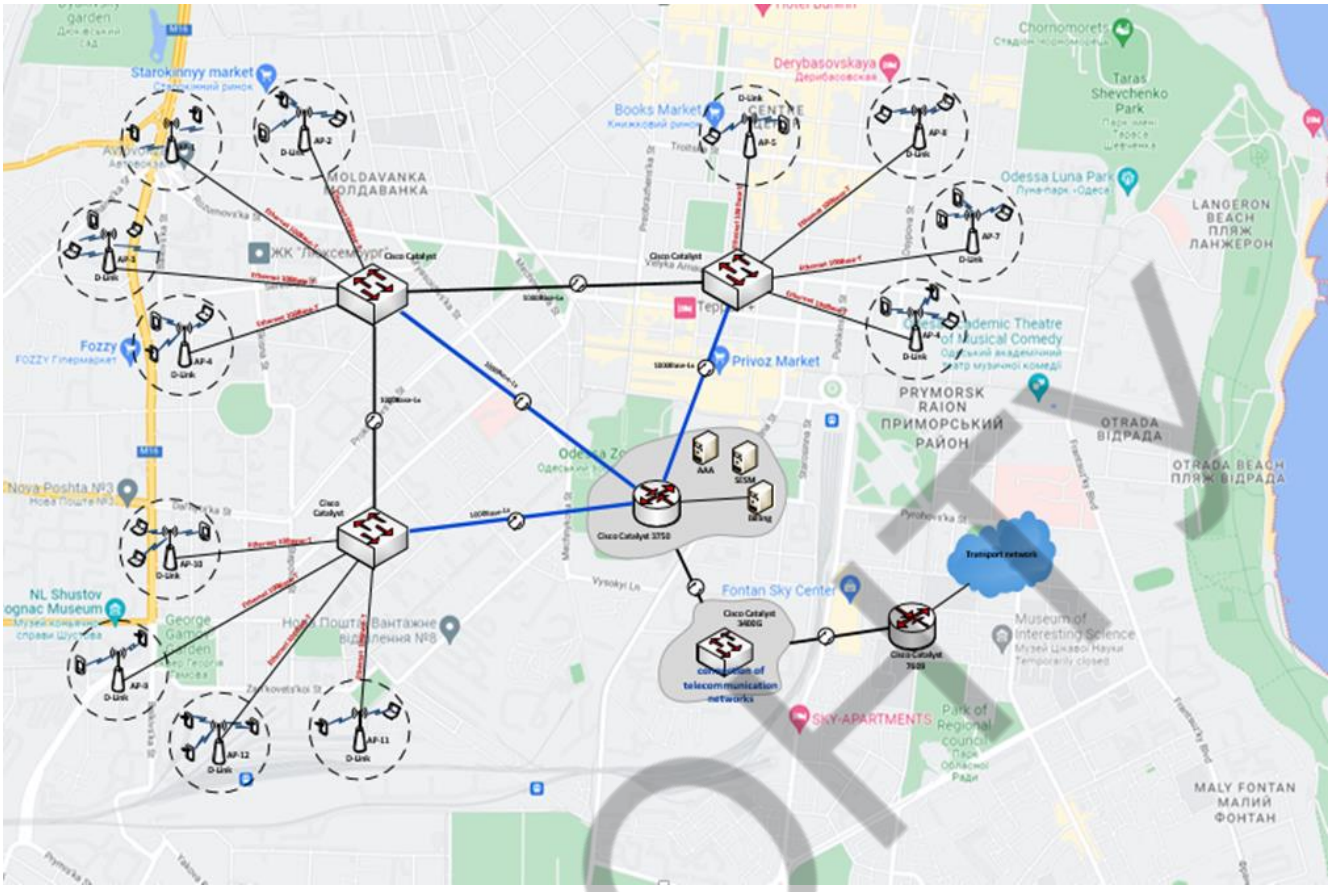

Fig. 5. Plan-map with the topology of the network of hotspots in the Points of Invincibility

Table 1 - Placement of access points in Points of Invincibility in Odesa

Numbering access points	Type of access point	Address of the Point of Invincibility
AP-1	D-Link AC2600 DWL 8620AP	Mala Arnautska, 2
AP-2	D-Link AC2600 DWL 8620AP	Pyrahovska, 3
AP-3	D-Link AC2600 DWL 8620AP	Seminarska, 1/5
AP-4	D-Link AC2600 DWL 8620AP	Staroportofrankivska, 103 a
AP-5	D-Link AC2600 DWL 8620AP	Spiridonivska, 12
AP-6	D-Link AC2600 DWL 8620AP	Spiridonivska, 18/24
AP-7	D-Link AC2600 DWL 8620AP	Bazarna, 85
AP-8	D-Link AC2600 DWL 8620AP	Tyraspolska, 13
AP-9	D-Link AC2600 DWL 8620AP	Tyraspolska,19
AP-10	D-Link AC2600 DWL 8620AP	Bryhadna, 56
AP-11	D-Link AC2600 DWL 8620AP	Sudnobudivna,11
AP-12	D-Link AC2600 DWL 8620AP	Komarova, 6

IV. RESULTS

Calculations were carried out for one segment per peak hour (PH).

It is planned to provide multi-service services (Triple Play Service) of high-speed data transmission, video images and multimedia in the broadband radio access network for Points of Invincibility.

The number of subscribers in one service segment in the PH can range from 40 to 70 subscribers. Wi-Fi network services are mainly focused on data transmission, where the main category of subscribers are those who use laptops or smartphones. Therefore the most significant number of subscribers use medium-speed services, about 80% of users, video image transmission services are less popular up to 10%, high-speed services used by about 5% of users.

For the calculation, we will take the value of the number of NAP= 50 subscribers who will receive:

Medium-speed interactive multimedia (MSIM) services: Access to the Internet, Email, File sharing;

High-speed multimedia (HSM): Video conferences, Video surveillance, VPN services;

High-speed interactive multimedia (HSIM): High-speed Internet, AoD services, GoD services;

Over high-speed multimedia (OHSM): Access to IP TV, Tape video, VoD services.

The following data were used for the calculation:

$N_{MSIM\ AP} = 0.8 \cdot N_{AP} = 0.8 \cdot 50 = 40;$

$N_{HSM\ AP} = 0.10 \cdot N_{AP} = 0.1 \cdot 50 = 5;$

$N_{HSIM\ AP} = 0.05\ 50 = 3;$

$N_{OHSM\ AP} = 0.05 \cdot NAP = 0.05 \cdot 50 = 2.$

Each service is characterized by the following indicators:

1) R, upload Mbit/s - upstream transmission speed;
2) R, download, Mbit/s - downstream transmission speed;
3) Ti, s - average session duration;
4) Ci - the average specific total number of service requests;
5) Yi, Earl - the average specific total load.

To solve this problem, we choose an empirical model, choose receiving and transmitting equipment, use MS Excel spreadsheets and calculate the maximum speed of receiving services by users in the area of operation of one point of the hotspot network for Points of Invincibility in the PH and compare it with the capabilities of mobile Internet in Ukraine. The result of the MS Excel computer model calculations is presented in Fig. 6.

In 2023, Ukraine ranks 128th in the world in terms of mobile Internet speed, according to the Speedtest Global Index [8]. According to Speedtest, the average speed of mobile Internet in Ukraine is 11.97 Mbit/s per second when downloading information from the network to the user (download), and 7.84 Mbit/s when uploading information from the user to the network (upload).

The obtained research results correspond to average statistical data in Ukraine.

	Expected intensity of receiving requests for the service download, Earl, Y	Bandwidth required, Mbit/s, R download	Expected intensity of receiving requests for the service upload, Earl,	Bandwidth required, Mbit/s, R upload	Bandwidth required, Mbit/s, R_S
MSIM	6	1,536	6	0,384	1,92
	10	2,56	10	0,64	3,2
	10	2,56	10	0,64	3,2
HSM	0,15	0,225	0,15	0,0192	0,2442
	0,15	0,225	0,15	0,0192	0,2442
	0,75	1,125	0,75	0,096	1,221
HSIM	0,9	1,8	0,9	0,23	2,03
	0,024	0,048	0,024	0,006	0,054
	0,9	1,8	0,9	0,23	2,03
OHSM	0,4	2,4	0,4	0,6	3
	0,4	2,4	0,4	0,6	3
	0,4	2,4	0,4	0,6	3
Total by segment of the network of hot spots			30,074		23,14

Fig. 6. Calculation of bandwidth of one segment of the network of ho spots for Points of Invincibility in the PH.

V. CONCLUSIONS

With the advent of the global Internet, society reached a new level, an information revolution took place. In connection with the rapid development of the information base, the market for providing high-speed and reliable access to the Internet is also developing rapidly.

The topicality of the subject is due to the fact that now there is a need to provide hotspot services in Points of Invincibility.

Wi-Fi technology has a large number of advantages, including: high speed of deployment, the possibility of gradual development of the network, starting with a minimal configuration, low operating costs, and high bandwidth.

The computer model for calculating the main parameters in MS Excel spreadsheets has been tested for the scenario of creating a radio access network based on D-LINK AC2600 DWL 8620AP access points that meet European and Ukrainian standards with the following qualities:

1) the network of hotspots (Wi-Fi) must provide visitors of Points of Invincibility with high-quality types of modern services, in particular, high-speed access to the Internet;

2) the network is able not only to withstand the load of one user with this service with a bandwidth of 23.14 Mbit/s, which is comparable to the capabilities of mobile Internet in Ukraine, but also has the possibility of further development.

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DEVELOPMENT OF EQUIPMENT FOR THE FORMALIZATION OF THE PROCESS OF SELECTING INFORMATION FEATURES FOR DISPLAYING INFORMATION ABOUT THE AIR SITUATION

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Abstract. *The work developed a formalized knowledge model for determining signs of violation of airspace use rules. The situations that arise in the airspace are analyzed and the choice of the knowledge representation model is substantiated. The study was conducted using the developed structure of target instructions and an artificial neural network.*

Keywords: *decision support system, knowledge formalization, knowledge model, air traffic, hybrid knowledge model.*

I. INTRODUCTION

The work is devoted to the development of a formalization apparatus for solving the task of selecting information features, which is a necessary component in the construction of information models (IM), which are an element of the information support system (ISS) for assessing the actions of the air adversary (AAA) at control points (CP) of the Air Force (AF).

The task of selecting information features (IF) is inextricably linked to solving the task of recognizing operational-tactical situations (OTS). As a result, the question of formalizing the recognition procedure arises.

II. LITERATURE ANALYSIS

The results of the analysis of modern research in the field of automation of air traffic control show that great attention is paid to the issue of improving of the Information Support System(ISS) of the human operator. However, the problems of formalization of knowledge about the processes of recognition of situational situations (SS) have not yet been finally resolved. This primarily concerns the problem of adequate person, who making the decision (PMD) assessment of the general situation, which is in the area of responsibility of the control body of the automated air traffic control systems (AA TCS), as well as its components - air, meteorological, obstacle, ornithological and other types of situation.

2.1. Subsection title

Only that, the problem regarding the mechanism of safe detection of situational situations, which in the dynamics of development can lead to aviation events and disasters, under the condition of inefficient response of PMD to them, has not been finally resolved.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The main goal of recognition is the construction of effective computational models and methods of formalized descriptions of situations for assigning them to the appropriate classes with the help of information signs and procedures of logical deduction.

IV. RESULTS

1 Analysis of the sources of receiving information about the Air condition

The task of selecting information features for displaying information about the air situation is inextricably linked to solving the task of automating the decision-making procedure, regarding the recognition of situations that may arise in the air space. For this, it is necessary to formalize the process of determining the signs of violation of the rules for the use of airspace (SVRUA).

In order to formalize the process of determining the features of the SVRUA, it is necessary to analyze the system of collecting and processing information about software.

The main source of information about the air enemy is radio engineering troops (RET). Radio engineering troops are designed to conduct reconnaissance of airborne targets and issue information about the start of an air attack, as well as control flights and overflights of aircraft.

In a general form, the scheme of the software information collection and processing system is shown in Fig. 1.

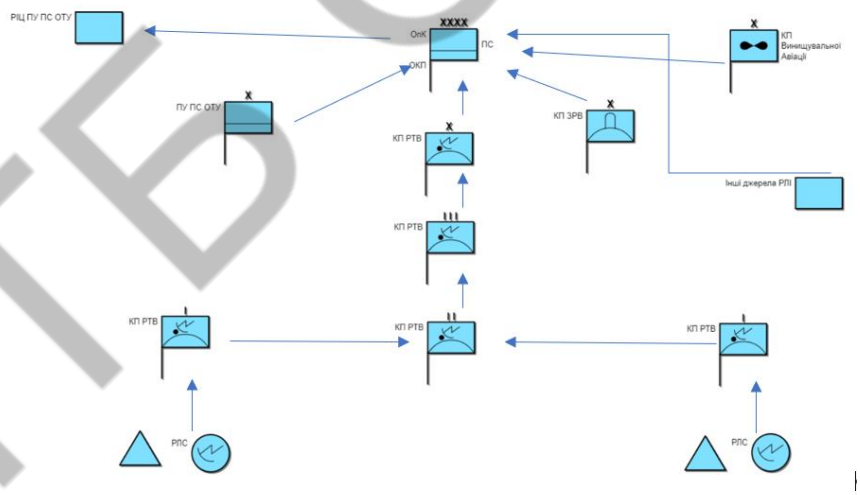

Fig. 1 General diagram of the system for collecting and processing information about the air situation

From the analysis of the given system, it follows that this system has several levels of generalization of information. The main sources of information about software are the control points of radar units (CP RC). At the highest level, the RET units process and generalize information about software received from subordinate units.

The next level of information processing is its processing in the units of units of the radio engineering troops, after which the received information is transferred to the operational and tactical control unit of the Air Force, where automatic and semi-automatic processing of software information takes place with the help of people on the next shift.

After processing the received information about the software in the area of responsibility of the AF OTM, it is displayed on the information display means to ensure decision-making by the relevant persons.

The list of main sources and consumers of information includes the following: radar stations; altimeters; ground radar interrogators; control points of radio technical units and interacting control points of radio technical parts and units of radio technical connections, which are equipped with complexes of automation means (CAM). Other sources of information about the Air Objects (AO) include reconnaissance aircraft, operational command units, units of the AF, border detachments stationed in the area of responsibility of the AF, etc. [4].

When formulating the task of decision-making regarding the identification of the features of the SVRUA in order to formalize it and develop appropriate programs, it is necessary to resolve the fundamental question of the appropriate (for such a system) distribution of functions between a human operator and an electronic computer (computer). For this, an analysis of informational and cognitive approaches to the automation of DMS tasks should be conducted, as well as determine the expediency of using a certain approach when considering this problem area [1].

The setting of decision-making tasks, with the information method, should assume their formalization using a small amount of quantitative initial data and signs. Computers rely on the functions of processing current information about the state of reality, presented in the form of data. All operations that require the use of knowledge about the properties of the environment and systems are performed by a person - the user, who makes decisions.

The informational approach is reflected in the provisions of the theory of rational decisions, which is developed by researchers, mathematicians and economists, it focuses on the use of computational procedures.

That’s why, it should be noted that the subject of its study is only the final stage of the decision-making process - the choice of the optimal (best) option and decision, assuming that all preparatory work, which requires the use of knowledge about objective reality, is performed by a person [1].

Cognitive (from Latin cognitio – knowledge, cognition), an approach based on knowledge, it became possible for implementation thanks to the development of AI ideas.

Features of the cognitive approach are that the computer can be assigned functions for formulating or determining the conditions for solving decision-making tasks, as well as finding solutions in unforeseen situations.

As a result of the specified features, the cognitive approach in the development of special mathematical support opens up the possibility of creating such control systems

that are distinguished by a high degree of adaptability to the external conditions of the environment, as well as the ability to self-learn.

Human functions in such systems consist in the creation of general mathematical support at the design stage, in the formalization and introduction of expert knowledge into the computer at the stage of setting up the system for a certain subject area. It should be noted that the use of a cognitive approach is absolutely unnecessary for finding solutions to open problems. Such an approach can be implemented in various forms - from systems that provide support for decision-making processes in dialogue mode with the user, to fully automatic systems that manage autonomous activities [4].

2. Development of the apparatus for the formalization of the knowledge model for the determination of signs of violations of the air space use

According to the rules for the use of airspace over the territory of Ukraine, logical-linguistic descriptions of the situations of air traffic within the limits of the responsibility of the MB OTM have been compiled, given in table 1. [2].

Table 1. Typical situations occurring in airspace

№	The name of the situation in the airspace	Description of the situation observed in the air space
1.	Regular (normal) situation	All air traffic objects are carried out in accordance with applications and traffic schedules
2.	The threat of an aerial object crossing the border	The air object is moving in the direction of the state border of Ukraine outside the declaration (without declaration) for flight
3.	Crossing the border by an aerial object	The air object crosses the state border of Ukraine with external ones, outside the declaration (without declaration) for the flight.
4.	Force majeure situation	The air object crosses the state border of Ukraine from the external, outside the declaration (without declaration) for a flight in connection with a force majeure situation.
5.	Hijacking of an aircraft (HA)	The aircraft moves in the direction of the state border from the territory of Ukraine without a declaration (without a declaration) for flight
6.	Violation of airspace use rules (VRUA)	The aircraft is moving in accordance with the flight application in violation of the rules for the use of airspace

They have the following description:

a) if the air object moves according to the application (schedule) for the flight in compliance with the established procedure and rules for the use of air space, then this situation is characterized as standard (S_o);

b) if the air object moves without an application (outside the schedule) for flight or violates the established procedure (rules) for the use of airspace, then this situation is characterized as irregular (S_1);

c) if the air object of another state moves without a request (out of schedule), and its current coordinates belong to the Z_P reconnaissance zone, and the extrapolated coordinates belong to the zone Z_T, then this situation can be characterized as a threat of crossing the state border $(S_{1.1})$;

d) if the air object of another state moves without an application (out of schedule), and its current coordinates belong to the zone Z_T, and the previous coordinates belonged to the zone Z_{Π}, then this situation can be characterized as crossing the state border $(S_{1.2})$;

e) if the air object of another state moves from the outside in the direction of the state border and a force majeure situation occurs on board it, then the situation can be characterized as force majeure $(S_{1.3})$;

f) if the air object moves according to the application (schedule) for the flight, but in violation of the procedure (rules) for the use of air space, then this situation can be characterized as a violation of the flight regime $(S_{1.4})$;

g) if there is information about the hijacking of an aerial object or it is moving in the direction of the state border, does not follow commands and its spatial coordinates belong, then this situation can be characterized as hijacking $(S_{1.5})$ [3].

The decision-making process in the management of complex objects and systems is inextricably linked to solving the task of recognizing situations. But the high complexity of recognition tasks does not allow us to consider the issue of their formalization as completely resolved.

The formalization of the process of determining the signs of SVRUA requires the selection of the knowledge representation model shown in Fig. 2 [2].

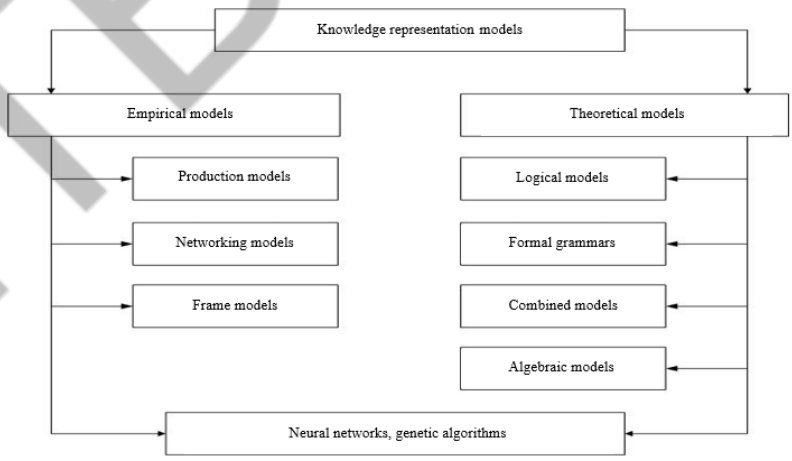

Fig. 2 Knowledge representation models

Because when building OT classes, one should take into account the fact that the number of ISes characterizing situations in the air space can be practically unlimited. A number of requirements must be made to the ISS: the set of ISSes must be necessary and,

at the same time, sufficient to describe the situations in the process of assessing the situation at the CP and allow the most complete presentation of the model of the problem area in the computer memory.

For the formalization of such tasks, it is appropriate to use network and logical models of knowledge. In particular, we are talking about the use of combined models based on the use of the structure of target instructions (STI) and the calculation of first-order predicates [4].

The main elements of this formalization apparatus are purpose and relation. The goal is the state of the subject area, which is characterized by: a set of states of objects of physical reality; a multitude of events; transition rules; actions that must be performed for the object to achieve a certain state [3].

However, STI has a number of disadvantages: the process of knowledge formalization is complicated; difficult implementation of the procedure for checking the consistency of the formalized description of software knowledge; the procedure for verifying the completeness of the formalized description; v-value of the pragmatic interpretation for each of the vertices of the STI; a non-formalized procedure for processing semantic (qualitative) information, which is used by experts, and replacing it with indicative (quantitative) information, which is used by the STI.

The formal apparatus of the number of predicates, which is used along with the STI [1], is practically devoid of the mentioned shortcomings.

At the same time, the model of knowledge, based on the calculation of first-order predicates, has the following advantages and disadvantages.

Advantages: ease of creation and understanding of separate product rules, ease of addition and modification of rules, simplicity of the mechanism of logical conclusion.

Disadvantages: vague clarity of the mutual relations of the rules, the difficulty of evaluating a holistic image of knowledge, low processing efficiency; lack of flexibility in logical conclusion.

However, to solve this problem, the possibility of using artificial neural networks (ANN) should be taken into account. ANNs are used to solve a fairly wide range of tasks, namely when solving problems of pattern recognition, both static and dynamic, as well as when analyzing incomplete and contradictory data. The main disadvantage of ANNs is limited opportunities for obtaining explanations about the process of making decisions.

For the process of determining the signs of SVRUA, it is necessary to analyze the totality of IO. These data can be divided into two groups:

– radar reconnaissance data: planar coordinates of AO at this moment in time (X_j^n, Y_j^n); AI flight height (H_j^n); speed of movement of AO (V_j^n); course of motion of AO (ψ_j^n); flight time (t^n_j); real flight application number (N_{3j}); the number of air objects that are actually in the air (Kj); presence or absence of a distress signal (Rj); sign of state affiliation (ДП); presence or absence of adverse weather conditions (Mj); the presence or absence of unfavorable ornithological conditions (Orj).

–dispatch control data: given height echelon ($\Delta H_з$); set flight speed ($\Delta V_з$); set flight course ($\Delta\psi_з$); the specified time interval of the flight of the air object over the corresponding points ($\Delta t_з$); planned flight application number (N зпл); the number of air objects specified in the flight application (Nз).

It is also necessary to take into account the location of the software in a certain area of responsibility of the MB OTM. Known spatial characteristics are used to divide the limits of responsibility of the Air Force into areas of air space: the radar field, the direction of alerting of duty forces, the limits of responsibility of the Air Force, as well as the flight corridors of the air object. Areas of responsibility of MB OTM are schematically depicted in Fig. 3.

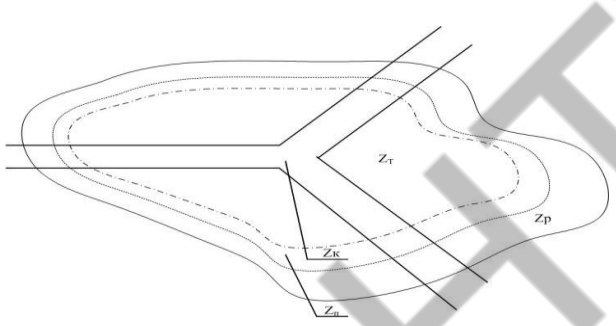

Fig. 3 Spatial representation of the boundary of responsibility of MB OTM

Each zone has certain characteristics: coordinates, area, etc. [2].

If the zone of responsibility is denoted by Zo, then the ratio describing its component parts (Fig. 3) can be represented by the following expression:

$$\{Z_P, Z_T, Z_П, Z_K\} \subset Z_O \tag{2.1}$$

Areas of responsibility of MB OTM are divided into: the airspace zone, which includes the flight corridors of the AO (Zk); the airspace zone directly above the territory of the MB (Z_T); the external border zone, which characterizes the bringing of regular forces of the MB to readiness No. 1 (Zп); reconnaissance zone of the windy space outside the territorial boundary of responsibility of the MB and zone Zп (Zp).

The regular (S_0) and non-regular (S_1) situation can be presented in the form of a formalized description:

$$\begin{aligned}&\left(\{X_i, Y_i\} \in Z_k\right) \cap \left(V_j \in \Delta V_з\right) \cap \left(H_j \in \Delta H_j\right) \cap \left(\Psi j \in \Delta \Psi j\right) \cap \left(t_j \in \Delta t_з\right) \cap \\ &\cap \left(N_{зj} = N_{зпл}\right) \cap \left(K_j = K_з\right) \cap \left(\mathrm{R_j} = 0\right) \Rightarrow S_0,\end{aligned} \tag{2.2}$$

$$\begin{aligned}&\left(\{X_i, Y_i\} \notin Z_k\right) \cap \left(V_j \notin \Delta V_з\right) \cap \left(H_j \notin \Delta H_j\right) \cap \left(\Psi j \notin \Delta \Psi j\right) \cap \left(t_j \notin \Delta t_з\right) \cap \\ &\cap \left(N_{зj} \neq N_{зпл}\right) \cap \left(K_j \neq K_з\right) \cap \left(\mathrm{R_j} = 1\right) \Rightarrow S_1.\end{aligned} \tag{2.3}$$

$$\begin{aligned}&\left(\{X_i, Y_i\} \notin Z_k\right) \cap \left(V_j \notin \Delta V_з\right) \cap \left(H_j \notin \Delta H_j\right) \cap \left(\Psi j \notin \Delta \Psi j\right) \cap \left(t_j \notin \Delta t_з\right) \cap \\ &\cap \left(N_{зj} \neq N_{зпл}\right) \cap \left(K_j \neq K_з\right) \cap \left(\mathrm{R_j} = 1\right) \Rightarrow S_1.\end{aligned} \tag{2.4}$$

The threat of crossing the state border:

$$\left(\{X_i, Y_i\} \in Z_p\right) \cap \left(N_{зj} \neq N_{зпл}\right) \cap \left(\left\{X_i^{\epsilon}, Y_i^{\epsilon}\right\} \in Z_T\right) \cap \left(\text{ДП}_\text{j} = 0\right) \Rightarrow S_{1.1} \tag{2.5}$$

Crossing the state border:

$$\left(\{X_i, Y_i\} \in Z_T\right) \cap \left(N_{зj} \neq N_{зпл}\right) \cap \left(\{X_i^{'}, Y_i^{'}\} \in Z_П\right) \cap \left(\text{ДП}_\text{j} = 0\right) \Rightarrow S_{1.2} \quad (2.6)$$

Force majeure situation:

$$\left(\{X_i, Y_i\} \in Z_p\right) \cap \left(N_{зj} \neq N_{зпл}\right) \cap \left(\{X_i^{e}, Y_i^{e}\} \in Z_П\right) \cap \left(\text{R}_\text{j} = 1\right) \cap \left(\text{ДП}_\text{j} = 0\right) \cap$$
$$\cap \left(M = 1\right) \cap \left(Or = 1\right) \Rightarrow S_{1.3}. \quad (2.7)$$

Flight mode violation:

$$\left(\{X_i, Y_i\} \notin Z_k\right) \cap \left(V_j \notin \Delta V_з\right) \cap \left(H_j \notin \Delta H_j\right) \cap \left(\Psi j \notin \Delta \Psi j\right) \cap \left(t_j \notin \Delta t_з\right) \cap$$
$$\cap \left(N_{зj} = N_{зпл}\right) \cap \left(K_j \neq K_з\right) \cap \left(\text{R}_\text{j} = 0\right) \Rightarrow S_{1.4}. \quad (2.8)$$

Aircraft hijacking:

$$\left(\{X_i, Y_i\} \in Z_T\right) \cap \left(\{X_i^{e}, Y_i^{e}\} \in Z_P\right) \cap \left(\{X_i^{e}, Y_i^{e}\} \in Z_П\right) \cap \left(\text{B}K = 0\right) \Rightarrow S_{1.5}. \quad (2.9)$$

Analysis of the descriptions given in subsection 2.1 allows to reveal the relationship between disparate current data, the combination of which makes it possible to detect abnormal situations in the airspace.

The following ratios can be found from the description of the staffing situation:

A) relation of belonging ($\in$):

– current plane coordinates of the AO (X_i, Y_i) to the flight corridors (Z_K), which is determined by the ratio:

$$\left(X_i, Y_i\right) \in Z_k, \quad (2.9)$$

– AO flight height (H_j) to the given height echelon (ΔH_j), which is determined by the ratio:

$$\left(H_j \in \Delta H_j\right), \quad (2.10)$$

– the speed of movement of AO (V_j) of the given flight speed $(\Delta V_з)$, which is determined by the ratio:

$$\left(V_j \in \Delta V_з\right), \quad (2.11)$$

– the course of movement of AO (Ψj) according to the given flight course $(\Delta \Psi j)$, which is determined by the ratio:

$$\left(\Psi j \in \Delta \Psi j\right) \quad (2.12)$$

– compliance of the flight time (t_j) of the given points with the given time interval $(\Delta t_з)$, which is determined by the ratio:

$$\left(t_j \in \Delta t_з\right) \quad (2.13)$$

B) similarity ratio (=):

– number of the application (schedule) for the actual $(N_{зj})$ and scheduled $(N_{зпл})$ flight, which is determined by the ratio:

$$\left(N_{зj} = N_{зпл}\right) \quad (2.14)$$

– the number of AOs (K_j) that are actually in the air and specified in the flight application $(K_з)$, which is determined by the ratio:

$$(K_j = K_з) \tag{2.15}$$

C) ratio of presence (absence):

– absence of signs of distress on board the aircraft, which is determined by the ratio:

$$(\mathrm{R_j} = 0) \tag{2.16}$$

If at least one relationship from the description of the regular situation is not fulfilled, then such a situation characterizes any non-regular situation.

The following ratios can be found from the description of the abnormal situation:

A) relation of belonging ($\in$):

– current planar coordinates of AO (X_i, Y_i), to the zone Z_p, which is determined by the ratio:

$$(X_i, Y_i \in Z_p) \tag{2.17}$$

– extrapolated planar coordinates of AO (X_i^e, Y_i^e), to the zone (Z_T), which is determined by the ratio:

$$(\{X_i^e, Y_i^e\} \in Z_T) \tag{2.18}$$

B) similarity ratio (=):

– state ownership of AO is "foreign", which is determined by the ratio:

$$(\text{ДП}_\text{j} = 0) \tag{2.19}$$

C) ratio of presence (absence):

– absence of signs of distress on board the aircraft, which is determined by the ratio (2.16).

From the description of the state border crossing situation, the following relationships can be identified:

A) relation of belonging ($\in$):

– current planar coordinates of AO (X_i, Y_i), to the zone Z_T, which is determined by the ratio:

$$(X_i, Y_i \in Z_T) \tag{2.20}$$

– of the previous planar coordinates of the AO (X_i', Y_i') to the zone $(Z_П)$, which is determined by the ratio:

$$(\{X_i', Y_i'\} \in Z_П) \tag{2.21}$$

B) similarity ratio (=):

– state ownership of software is "foreign", which is determined by the ratio (2.19)

C) ratio of presence (absence):

– absence of signs of distress on board the aircraft, which is determined by the ratio (2.16).

From the description of the situation characterized as force majeure, the following relationships can be identified:

– extrapolated planar coordinates AO (X_i^e, Y_i^e) to the zone $(Z_П)$, which is determined by the ratio:

$$\left(\{X_i^e, Y_i^e\} \in Z_П\right) \tag{2.22}$$

– current planar coordinates of AO (X_i, Y_i), to the zone Z_P, which is determined by relation (2.17).

A) similarity ratio (=):

– state ownership of AO is "foreign", which is determined by the ratio (2.19)

B) ratio of presence (absence):

– the absence of adverse weather conditions is determined by the ratio:

$$(M = 0) \tag{2.23}$$

– the absence of an unfavorable ornithological situation is determined by the ratio:

$$(Or = 0) \tag{2.24}$$

– the presence of signs of distress on board the aircraft, which is determined by the ratio:

$$(\mathrm{R_j} = 1) \tag{2.25}$$

From the description of the situation that determines the violation of the flight regime, the following ratios can be identified:

A) relation of belonging ($\in$):

– current planar coordinates of the AO (X_i, Y_i) to the flight corridors (Z_K), which is determined by the ratio (2.9);

– AO flight height (H_j) to the specified height echelon (ΔH_j), which is determined by the ratio (2.10);

– the speed of movement (V_j) of the given flight speed $(\Delta V_з)$, which is determined by the ratio (2.11);

– the course of movement (Ψj) according to the given flight course $(\Delta \Psi j)$, which is determined by the ratio (2.12);

– compliance of the flight time (t_j) of the given points with the given time interval $(\Delta t_з)$, which is determined by the ratio (2.13);

B) similarity ratio (=):

– number of the application (schedule) for the actual $(N_{зj})$ and scheduled $(N_{зпл})$ flight, which is determined by the ratio (2.14);

– the number of AOs (K_j) that are actually in the air and specified in the flight application $(K_з)$, which is determined by the ratio (2.15);

C) ratio of presence (absence):

– absence of signs of distress on board the aircraft, which is determined by the ratio (2.16).

From the description of the situation that defines the Air Force, the following ratios can be identified:

A) relation of belonging ($\in$):

– current planar coordinates of AO (X_i, Y_i), to the zone Z_T, which is determined by relation (2.20);

– extrapolated planar coordinates AO (X_i^e, Y_i^e), to the zone $(Z_П)$, which is determined by the ratio (2.22);

– of the extrapolated planar coordinates AO (X_i^e, Y_i^e), to the zone (Z_P), which is determined by the relation (2.18):

$$\left(\left\{X_i^e, Y_i^e\right\} \in Z_P\right) \tag{2.26}$$

B) similarity ratio (=):

– state ownership of AO is "own", which is determined by the ratio:

$$\left(ДП_j = 1\right), \tag{2.27}$$

C) ratio of presence (absence):

– absence of signs of distress on board the aircraft, which is determined by the ratio (2.16);

– non-fulfillment of commands transmitted on board the aircraft is described by the ratio:

$$\left(BK = 0\right), \tag{2.28}$$

Based on the above ratios, it is possible to draw up a structure of target instructions for determining the signs of violation of the air use rules (Addition B.1).

It can be seen from the figure that the use of initial conditions necessitates the development of means for inputting initial data.

The main markings in Fig. 4 are:

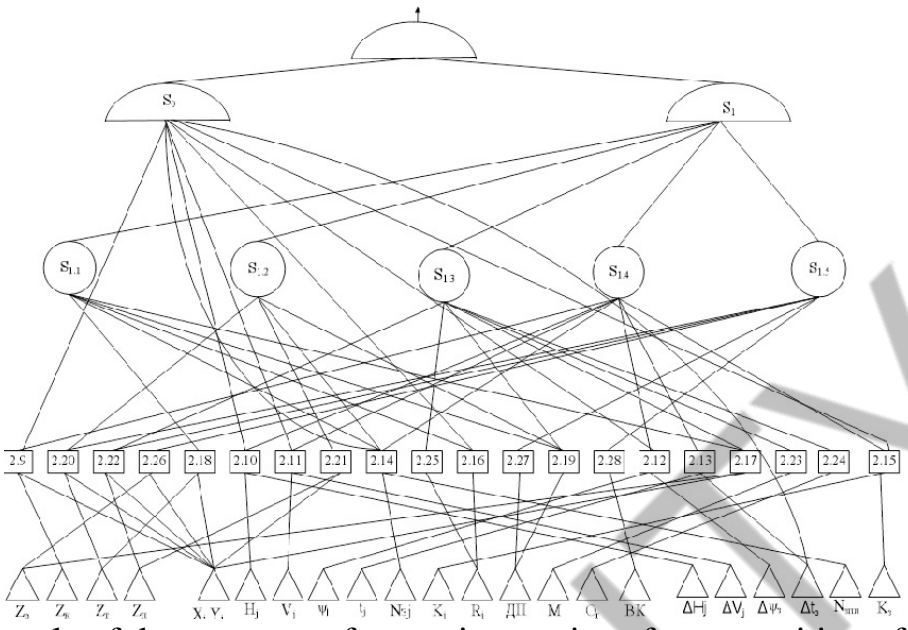

Fig. 4 Example of the structure of target instructions for recognition of situations in airspace

– initial conditions;
– vertices of comparison;
– vertices of the OR type;
– top of type I

Vertices AND and OR are used to implement logical generalizations of comparison results.

In order to assess the quality of solving the situation recognition task, an experiment should be conducted, for which the developed functional network and artificial neural network should be used.

Depending on the adopted method of describing a priori data, different recognition algorithms can be built. Most often, the mathematical apparatus of fuzzy sets is used to describe a priori summaries. The formalized description of quantitative features is represented by the function of belonging to the value of the features in the form of a fuzzy LR-interval. An example of such a representation is given in Fig. 5

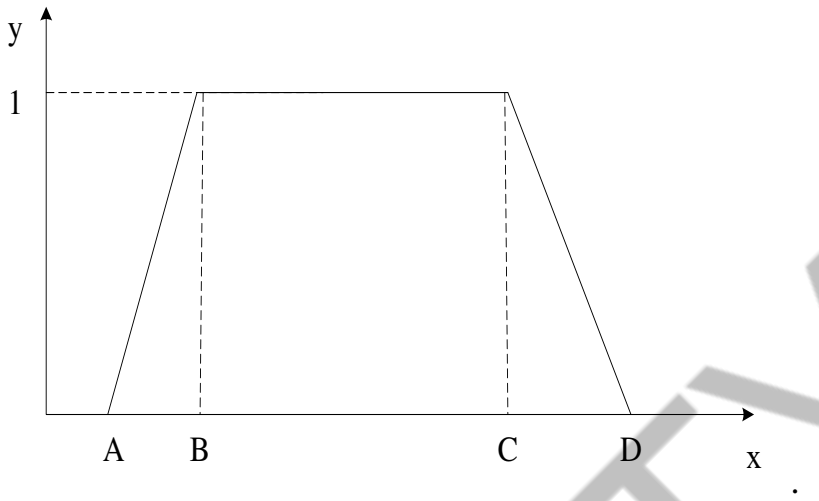

Fig. 5 Distribution function of possible parameter values

In Fig. 5, values B and C represent the lower and upper limits of the most likely values of the characteristic, and A and D are the minimum and maximum values of the characteristic.

The description of feature values using LR-intervals has the following advantages: the possibility of presenting features with stochastic and non-stochastic uncertainty; ease of description from the user's point of view; high expressiveness in terms of descriptive possibilities; ease of subsequent use when creating software modules.

Numerical values of quantities A, B, C and D are quite often determined on the assumption that the characteristic value has a normal distribution law. At the same time, the assumed parameters of the fuzzy LR-interval can be determined assuming that points B and C are two standard deviations from the mean value of parameter x, and points A and D are three standard deviations away. The coordinates of the areas of responsibility of MB OTM are presented in the form of RL-intervals presented in table 4.

Table 4. Coordinates of the area of responsibility of the MB OTM are presented using RL-intervals.

Flight zones	LL	LR	RL	RR
Zk X	6000	6500	6700	7200
Zk Y	1000	4500	4700	5200
Zт X	7200	8000	9000	9200
Zт Y	5200	6000	7000	7200
Zп X	9200	10000	11000	12000
Zп Y	7200	8000	9000	10000
Zp X	12000	13000	14000	16000
Zp Y	10000	11000	12000	14000

After determining the features of some object (situation), it is necessary to assign the observed object to some class of situations based on available a priori data and a posteriori summaries.

Making a decision about the situation in the airspace for each functional network (FN_{1-6}) is carried out using the following operations:

$$\Phi M_1 = \prod_{i=1}^{n} \overline{D}j + \prod_{i=1}^{n} \overline{Fj}, \quad (2.29)$$

$$\Phi M_2 = \sum_{i=1}^{n} \overline{D}j \cdot \sum_{i=1}^{n} \overline{Fj}, \quad (2.30)$$

$$\Phi M_3 = \max(\min(x_i y_i)), \quad (2.31)$$

$$\Phi M_4 = \frac{\sum_{i=1}^{n} \overline{D}j\overline{Fj}}{N}, \quad (2.32)$$

$$\Phi M_5 = \min(\max(x_i y_i)), \quad (2.33)$$

$$\Phi M_6 = \frac{\sum_{i=1}^{n} (\overline{D}j\overline{Fj}) - \prod_{i=1}^{n} (\overline{D}j\overline{Fj})}{1 + \sum_{i=1}^{n} (\overline{D}j\overline{Fj}) - 2 \cdot \prod_{i=1}^{n} (\overline{D}j\overline{Fj})} \quad (2.34)$$

Taking into account the above data, it is possible to carry out testing to evaluate functional networks in view of the number of correctly defined situations. A diagram was constructed that shows the effectiveness of FN_{1-6} in solving the task of recognizing situations (Fig. 6).

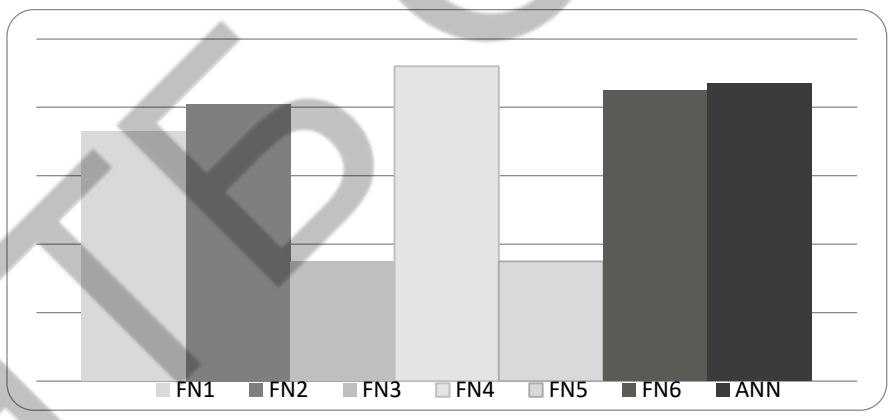

Fig. 6 Results of the functional network and artificial neural network recognition algorithm

We will analyze functional networks. Let's set a threshold value equal to 0.5. FN_3 and FN_5 have a too low coefficient of correct identification of situations, that is, they are not effective. This is due to the logical rules used in FN data. If at least one value equals 0, the other values are not taken into account.

The functional network developed in this way is able to correctly recognize 37-90% of situations.

However, as mentioned above, ANN is widely used to solve the problem of situation recognition.

The MATLAB simulation package was used to solve the problem of situation recognition using ANN.

ANN is a multi-layer forward propagation perceptron without feedback. This type of ANN is quite often used to solve the tasks of recognition, classification and management [4]. The created ANN was trained by the method of backpropagation of errors [2].

A training sample was formed to adjust the parameters of the ANN for the solution of the situation recognition task. The training sample was drawn in such a way as to reflect the main characteristics of the situations. The training of the network was carried out using those data that clearly identified this or that situation.

After filling the database with examples from the test sample, each recognition system was tested and the probability of correct recognition was determined for each method.

The results of the experiment revealed that the probability of correctly recognizing the situation in the airspace when using ANN was 88%.

V. CONCLUSIONS

In this work, a data formalization apparatus was developed and a knowledge formalization model was developed in the form of a structure of target instructions for a formalized description of the process of solving the task of recognizing situations that may arise in the airspace in the area of responsibility of the MB OTM. An experiment was conducted using the developed structure of target instructions and an artificial neural network. It is more appropriate to use a trained ANN to solve the task.

Solving the task of selecting information features is a necessary component in the construction of information models. Defining the list of information features that will ensure the decision-making process and justifying the composition of information elements is the main component in creating an information model to support decision-making. Therefore, the work has developed a procedure for selecting information features that are necessary and sufficient for solving the tasks of recognizing situations in the airspace and evaluating the actions of the air adversary.

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APPLICATION OF FUZZY LOGIC FOR AUTOMATED FAULT-FINDING IN THE POWER SUPPLY NETWORK

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Abstract. *In case of damage, the switching device at the transformer substation disconnects the voltage along the entire line where the damage occurred. Then there is the problem of finding the location of the damage. Existing technical means of locating places of damage in the conditions of great length and branching of distribution networks of Ukraine are quite expensive. Therefore, the task of finding damage by other, less expensive, methods is currently relevant.*

One of the best ways to reduce the negative impact of damage is to reduce the total time of their search and elimination over a period of operation. A particularly important role in this is played by the means of determining the location of the damage (VMP). In the conditions of rough terrain, weak development of a road network, in the presence of power lines of considerable length successful VMP allows to reduce time of search of damage several times. The work is devoted to the topical problem of reducing losses from damage to power grids.

To achieve this goal, two tasks have been solved: the development of methods to support decision-making to determine the location of damage to the grid, the practical implementation of the method.

The first problem is solved on the basis of the theory of fuzzy sets, fuzzy inference. It is proposed to divide each power transmission line into sections. Determine the degree of risk of damage for each site using a fuzzy inference. In the system of fuzzy logical inference, both constant factors of influence (topological, anthropogenic) and variables (climatic conditions) in fuzzy form are used. As a result, in case of damage to the network according to certain degrees of risk, the route of movement of the operational - exit team is formed on the principle of "from the area with the highest to the area with less risk of damage."

The second problem is solved with the help of the MatLab package. The method was tested on the example of its application to a specific 10 kV power grid. The developed technique does not replace expensive means of detecting damage, but is a fairly cheap way to obtain additional information for the network manager. The technique is open to improvement and training during operation.

Key words*: logical control, network damage, mathematical model, software implementation, power line.*

I. INTRODUCTION

In the conditions of market relations between suppliers and consumers of electricity, one of the consequences of emergency power outages is compensation for losses to consumers. Ukrainian legislation provides for the material liability of suppliers to consumers, including the liability of electricity supply organizations. In judicial practice, there have been several cases of satisfaction of consumer claims for damages from the lack of electricity supply from the electricity supply organization.

The main causes of damage to power grids, as well as insufficient level of safety, both humans and animals in contact with them, are [1]:

- imperfection of power supply schemes;
- imperfection of operating rules and their proper implementation;
- practical absence of protection and alarm systems for single-phase earth faults;
- practical lack of systems for diagnosing the state of isolation;
- high level of internal overvoltages;
- use of equipment that has exhausted its regulatory resources.

The most vulnerable in Ukraine are 10 kV distribution networks.

In case of damage, the switching device at the transformer substation disconnects the voltage along the entire line where the damage occurred. Then there is the problem of finding the location of the damage. Existing technical means of locating places of damage in the conditions of great length and branching of distribution networks of Ukraine are quite expensive. Therefore, the task of finding damage by other, less expensive, methods is currently relevant.

One of the best ways to reduce the negative impact of damage is to reduce the total time of their search and elimination over a period of operation. A particularly important role in this is played by the means of determining the location of the damage (VMP). In the conditions of rough terrain, weak development of a road network, in the presence of power lines of considerable length successful VMP allows to reduce time of search of damage several times.

II. ANALYTICAL REVIEW OF THE LITERATURE

In the years since the creation of the first means of remote VMP, many domestic and foreign scientists have conducted research in this area.

Most devices based on insulation control [1-7] signal that there is a decrease in resistance in the network and are not able to selectively detect damage. Such methods can determine the distance to the place of damage, but in the conditions of an extensive distribution network it is not enough. Sometimes the task of locating the site of insulation damage is solved by sequential electrical disconnection of system elements with subsequent control of the insulation resistance of the disconnected element. With this method of searching for a damaged element there is a danger of failure of relay protection devices and automation, as well as the high cost of time of highly qualified personnel [2].

When solving the problem of protection of networks from single-phase short circuits, one of the main tasks is to optimize the neutral mode, as the method of neutral grounding not only determines the operating conditions of network insulation, but also affects the operation of automation and relay protection devices. which in turn create specific structures and schemes of earth fault protection devices. The lowest level of operational reliability corresponds to networks with completely isolated neutral [2]. For such networks in [2] the switching method is offered. The device, based on its use, allows you to continuously monitor the basic parameters of insulation and in the case of gradual deterioration of the latter (for example, with aging insulation) it becomes possible to predict that developing single-phase earth faults,

According to the Rules of technical operation of consumers' electrical installations, the operation of the network with a grounded phase is allowed until the damage is eliminated [8], and the operating personnel must find and eliminate the damage as soon as possible.

New information technologies can significantly speed up the process of finding the location of damage, if you use locking devices with the function of transmitting coded information and identifying the location and type of short circuit on the map-scheme of the dispatcher [9]. The use of such devices reduces the time of emergency mode and shortage of electricity, reduces costs by optimizing the route of the repair crew, reduces the environmental hazard of the environment from damaged power lines, it is possible to monitor unauthorized disconnection of lines or their sections. But in extensive distribution networks, the implementation of such an approach requires large enough funds. In addition, the methodology for remote determination of the location of damage to power grids is not effective enough because it is focused on ensuring a reliable VMP of a single transmission line. Much more effective is the system approach aimed at ensuring a reliable VMP on the power system complex with the use of additional information.

Therefore, monitoring of emergency parameters of overhead lines and weather conditions in the places of their operation, collection and storage of statistical data, forecast assessment of the technical condition of overhead lines are urgent tasks at the present stage [10 - 12].

Despite the significant amount of research on the issue of determining the location of damage to power lines remains relevant in view of the significant damage caused by emergency shutdown of power lines.

Improving existing and developing new methods and tools to control, detect and eliminate damage in distribution networks will help increase the reliability of power supply systems and improve the electrical safety of service personnel.

Thus, we can conclude that in all the variety of already established methods for detecting damage to power grids, it is still necessary to create more universal, accurate, easily corrected, as well as less expensive methods. This is the method proposed in this paper, based on fuzzy logic and fuzzy set theory.

III. OBJECT, SUBJECT AND RESEARCH METHODS

The purpose of the work is to assess the possibility of applying methods of fuzzy logic control for finding damage in the power supply network.

The object of the study is the process of detecting and locating faults (damages) in the power supply network.

The subject of the study is a mathematical model and software implementation of the method of localization of power grid damage based on fuzzy logic.

Research methods. When solving general and partial scientific tasks, the following are used: elements of the theory of fuzzy sets, the concept of a linguistic variable, a fuzzy logical conclusion, numerical methods of analysis with the use of computer technology.

The peculiarity and practical significance of the obtained results lies in bringing theoretical developments to practical implementation, which can be used by the operating staff of 6-10 kV power lines.

IV. THEORETICAL JUSTIFICATION OF THE METHOD

The task is to develop a certain expert system, which would be implemented in the form of a fuzzy inference system [13 - 15] and would determine the location of damage in the power supply network based on measurement data and additional data of both formal and informal nature.

Factors on which the occurrence of transmission line damage depends can be divided into two categories: constant and variable. Constant factors depend on topological conditions, human influence. Variable factors are mainly the influence of meteorological operating conditions.

It is proposed to divide each of the transmission lines into approximately equal lengths. For each site in the operational mode are determined meteorological parameters that affect the possible break of the transmission line, in the form of fuzzy linguistic variables [13]: "wind speed", "precipitation", "icing", "temperature". Also set the parameters that determine the geophysical and other features of the localization of the grid: "proximity to forests", "proximity to settlements", "proximity to roads", "proximity to water bodies". This list of parameters can be supplemented taking into account the specifics of a particular power supply network. The fuzzy linguistic variable "damage occurrence" is selected as the initial parameter.

The following terms have been introduced for each of the linguistic variables: "low", "medium", "high". The type of membership functions is trapezoidal (Fig. 1).

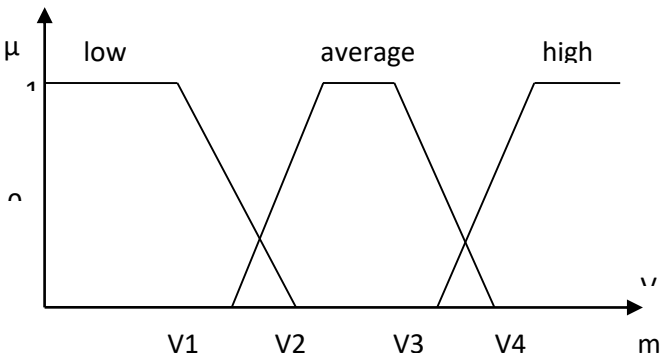


Fig.1. Functions of belonging to the fuzzy linguistic variable "wind"

The membership function of the terms "low", "medium" and "high" variable "wind speed" is calculated as follows:

$$\mu_{Vн} = \max\left(\min\left(1; \frac{V_2 - V}{V_2 - V_1} \right), 0 \right). \quad (1)$$

$$\mu_{Vср} = \max\left(\min\left(\frac{V - V_1}{V_2 - V_1}; \frac{V_3 - V}{V_4 - V_3}; 1 \right), 0 \right). \quad (2)$$

$$\mu_{Vв} = \max\left(\min\left(\frac{V - V_3}{V_4 - V_3}; 1 \right), 0 \right). \quad (3)$$

The values of the parameters of the membership functions are determined by experts. The membership functions of terms of other linguistic variables are constructed similarly.

For "ice":

$$\mu_{Обн} = \max\left(\min\left(1; \frac{Об_2 - Об}{Об_2 - Об_1} \right), 0 \right). \quad (4)$$

$$\mu_{Обср} = \max\left(\min\left(\frac{Об - Об_1}{Об_2 - Об_1}; \frac{Об_3 - Об}{Об_4 - Об_3}; 1 \right), 0 \right). \quad (5)$$

$$\mu_{Обв} = \max\left(\min\left(\frac{Об - Об_3}{Об_4 - Об_3}; 1 \right), 0 \right). \quad (6)$$

For "air temperature":

$$\mu_{Tн} = \max\left(\min\left(1; \frac{T_2 - T}{T_2 - T_1} \right), 0 \right). \quad (7)$$

$$\mu_{Tср} = \max\left(\min\left(\frac{T - T_1}{T_2 - T_1}; \frac{T_3 - T}{T_4 - T_3}; 1 \right), 0 \right). \quad (8)$$

$$\mu_{\text{Тв}} = \max\left(\min\left(\frac{\text{T} - \text{T}_3}{\text{T}_4 - \text{T}_3}; 1 \right), 0 \right). \quad (9)$$

For "precipitation":

$$\mu_{\text{Он}} = \max\left(\min\left(1; \frac{\text{O}_2 - \text{O}}{\text{O}_2 - \text{O}_1} \right), 0 \right). \quad (10)$$

$$\mu_{\text{Оср}} = \max\left(\min\left(\frac{\text{O} - \text{O}_1}{\text{O}_2 - \text{O}_1}; \frac{\text{O}_3 - \text{O}}{\text{O}_4 - \text{O}_3}; 1 \right), 0 \right). \quad (11)$$

$$\mu_{\text{Ов}} = \max\left(\min\left(\frac{\text{O} - \text{O}_3}{\text{O}_4 - \text{O}_3}; 1 \right), 0 \right). \quad (12)$$

The values of the functions of belonging to permanent factors, such as "proximity to forest areas", "proximity to settlements", "proximity to roads", "proximity to water bodies" are determined expertly once based on analysis of the topological scheme of the grid.

The presence of a high level of the variable "occurrence of damage" is important for the task of identifying the location of damage, so you can ignore the values of the terms "low" or "medium".

Estimation of the level of "high" variable "occurrence of damage" for the j-th section of the i-th transmission line is as follows:

$$L_{i,j} = A3_i \wedge \begin{pmatrix} Об_{ні,j} \wedge V_{ві,j} \vee Об_{сі,j} \wedge \left(V_{сі,j} \vee V_{ві,j}\right) \vee Об_{ві,j} \wedge \\ \left(V_{сі,j} \vee V_{ві,j} \vee V_{ні,j}\right) \vee O_{ві,j} \vee T_{ні,j} \vee T_{ві,j} \vee \\ Л_{i,j} \vee P_{i,j} \vee H_{i,j} \vee Д_{i,j} \end{pmatrix}$$

$$\mu_{Li,j} = \min\left(\mu_{A3i}, \begin{pmatrix} \max(\min(\mu_{Обні,j}, \mu_{Vвв,j}), \min(\mu_{Обсі,j}, \\ \max(\mu_{Vсс,j}, \mu_{Vвв,j}); \min(\mu_{Обві,j}, \\ \max(\mu_{Vнн,j}, \mu_{Vвв,j}, \mu_{Vсс,j})); \\ \max(\mu_{Oві,j}, \mu_{Tні,j}, \mu_{Tві,j}, \mu_{Лі,j}, \mu_{Pі,j}, \\ \mu_{Нi,j}, \mu_{Дi,j}) \end{pmatrix} \right) \quad (13)$$

$$i = 1,...,m; \quad j = 1,...,n.$$

where Li, j - linguistic variable "damage" j - th section of the i-th transmission line, $\mu_{Li,j}$ - degree of belonging of the linguistic variable "damage occurrence" of the j-th section of the i-th transmission line, m - number of transmission lines in the network, n - number of allocated sections on each transmission line, AZi - operation of protection equipment (clear logical value the membership function of which takes the value of 0.1), Ob is the

level of icing, O is the level of precipitation, T is the level of air temperature, L is the proximity to the forest area, P is the proximity to the reservoir, H is the proximity to settlements, D is the proximity to roads, μ- membership functions, indices n, c, c - terms low, medium, high.

After conducting the above analysis of each section of each transmission line of the power supply network, we obtain the values of the membership functions of the high level of the variable "damage". The value of these membership functions reflects the degree of risk of damage to the site. This information can be used by the dispatcher when developing the route of the operational and exit team.

4.1. Practical implementation of the proposed technique in MatLab

The research of the developed technique was carried out on the example of the electric network, the scheme of which is shown in fig. 2. Each of the three 10 kV transmission lines is divided into approximately equal sections, the numbers of which are shown in this figure 2.

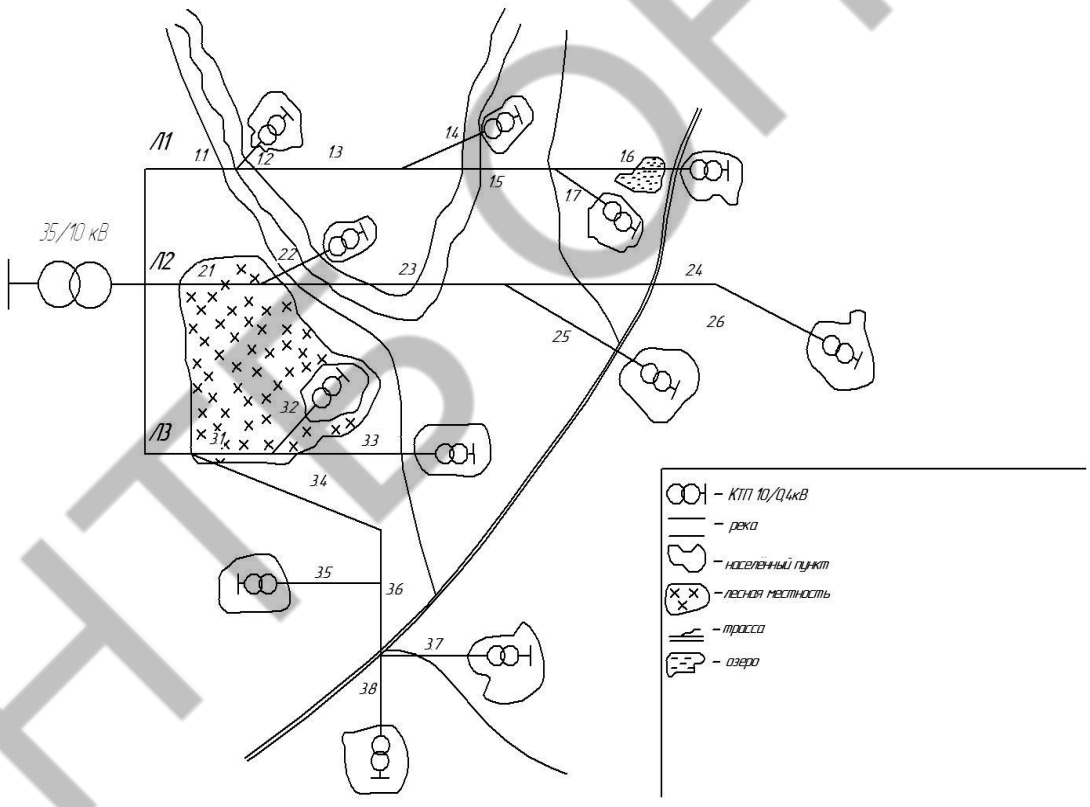


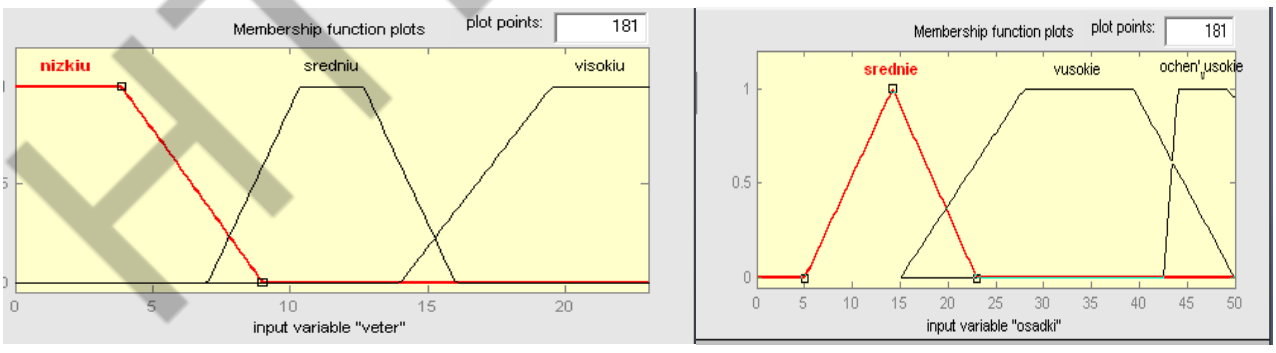
Fig. 2. Diagram of the power line

In the table. 1 shows expert estimates of fuzzy non-meteorological parameters.

Table. 1. The degree of risk of failure at each section of the transmission line on the relief features

	Relief features			
Power line sections	Proximity to forest areas JL	Proximity to water bodies µR	Proximity to settlements Mr.	Proximity to roads Ed
1.1	0.1	0.1	0.05	0.1
1.2	0	0.5	0.5	0.5
1.3	0	0.4	0.2	0.4
1.4	0	0.5	0.5	0
1.5	0	0.5	0.5	0.5
1.6	0	0.5	0.5	0.5
1.7	0	0.3	0.2	0.5
2.1	0.5	0	0.1	0.05
2.2	0.5	0.5	0.5	0.5
2.3	0.45	0.5	0.3	0.5
2.4	0	0.5	0.2	0.5
2.5	0	0	0.5	0.5
2.6	0	0	0.5	0
3.1	0.5	0	0	0
3.2	0.5	0	0.5	0
3.3	0.4	0	0.5	0.5
3.4	0.5	0	0.1	0.1
3.5	0.1	0	0.5	0.1
3.6	0	0	0.1	0.5
3.7	0	0	0.5	0.5
3.8	0	0	0.5	0.1

We model the process of assessing the risk of damage to the grid in the MatLab package [15, 16]. Fasification of meteorological parameters is presented in fig. 3.



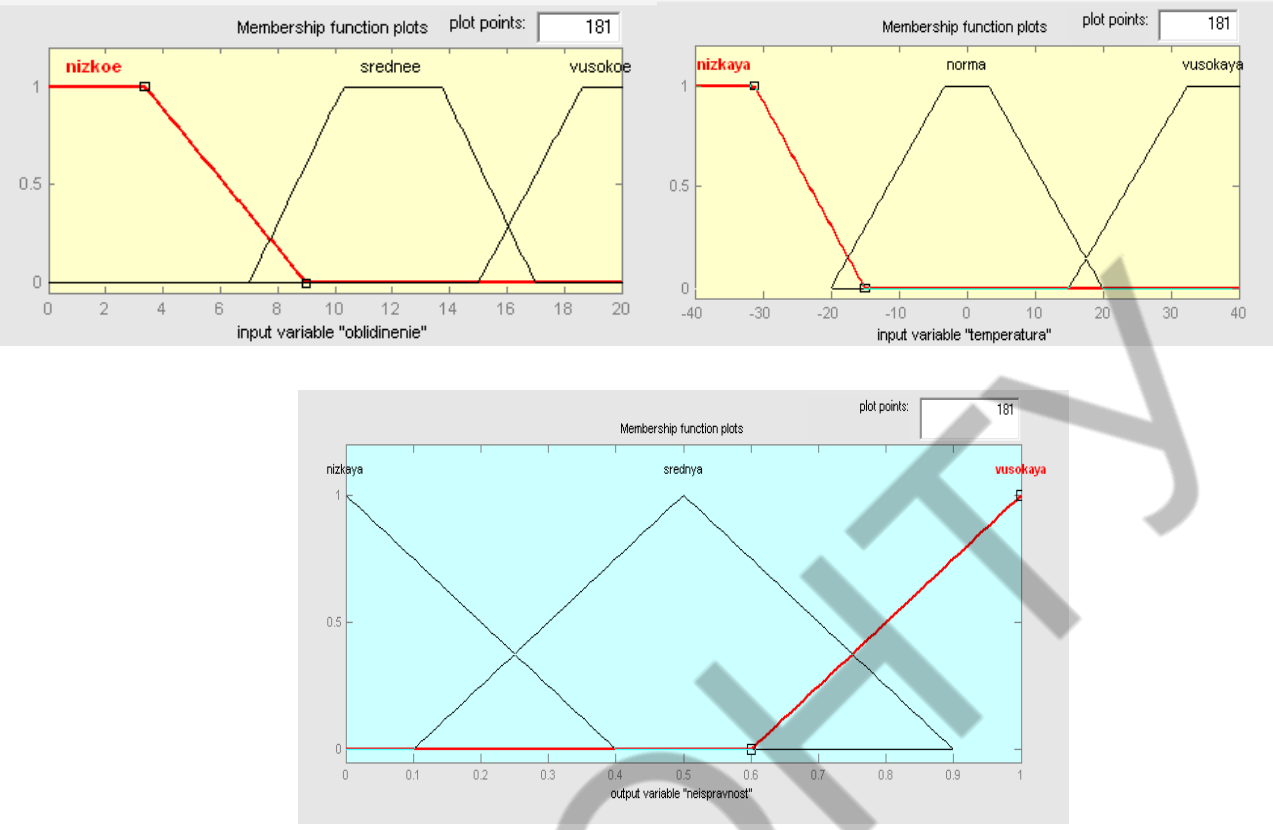


Fig. 3. Functions of belonging to the variables "wind", "precipitation", "icing", "temperature", "fault"

Then, according to (13), we determine the rules of fuzzy inference for each Fig. 4.

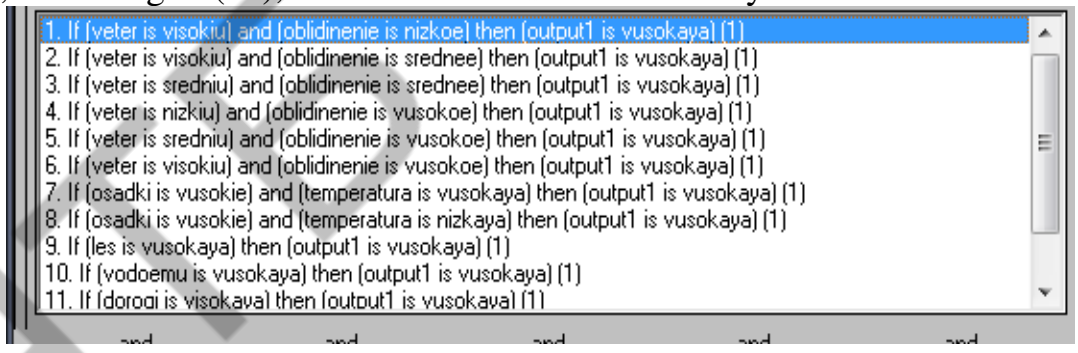


Fig. 4. Knowledge base in RuleEditor

As a result, we obtain the risk of damage to each section of the grid, as shown in Fig. 5.

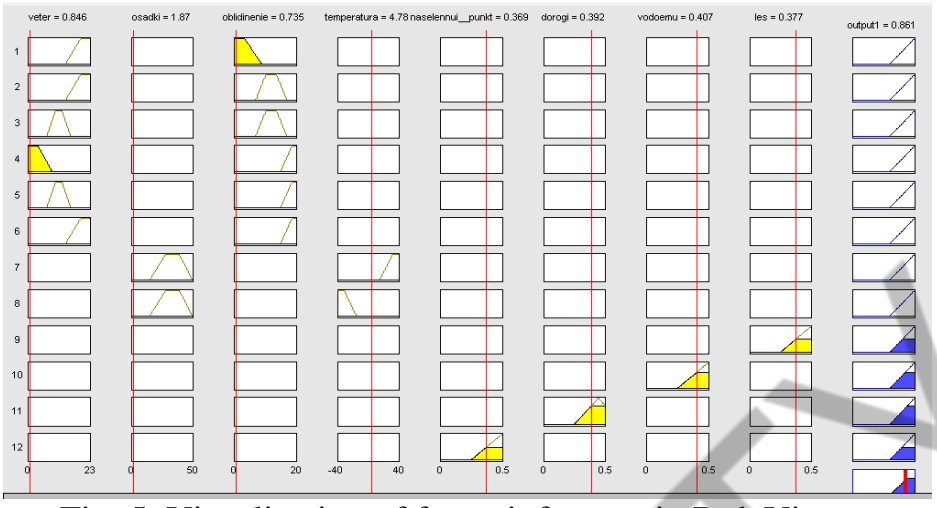


Fig. 5. Visualization of fuzzy inference in RuleViewer

To visualize the result, you can use the window to view the fuzzy output surface (Fig. 6).

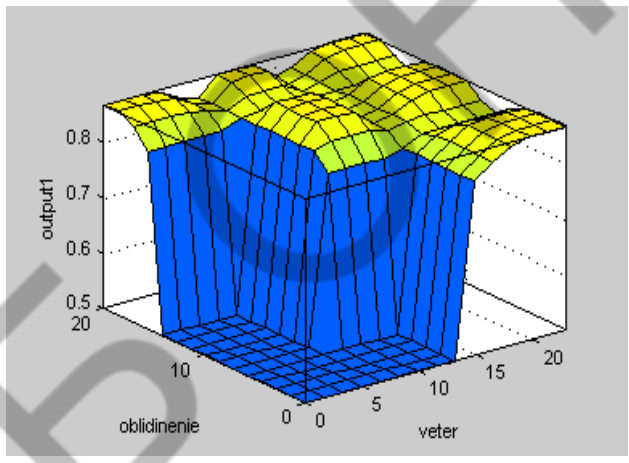


Fig. 6. Input-output surface in the SurfaceViwer window

To view the actual operation of the simulated system, consider a specific example with data obtained from the hydrometeorological service after damage to the power line (Table 2).

Table. 2. Values of input variables for each section of the transmission line

	Values of input variables			
sections of power lines	Wind speed, m / s	The amount of precipitation, mm / 12 h	Freezing on wires, mm	Temperature, 0C
1.1	13	15	2	-5
1.2	14	16	3	-6
1.3	13.5	15	3	-5.5
1.4	14	15.5	3.5	-6
1.5	14	16	4	-7
1.6	15	16	4.5	-7.5

1.7	13.5	14	2.5	-5
2.1	16	16	5	-7
2.2	15	15	4	-6
2.3	15.5	14	6	-10
2.4	14	13	4.5	-6
2.5	13	12	2	-5
2.6	13	12	1.5	-3
3.1	15	16	5	-5
3.2	17	15	2	-4
3.3	14.5	16	2	-5
3.4	17	13	1.5	-4
3.5	16	12	2	-5
3.6	19	10	3	-5
3.7	17	9	1	-4
3.8	16	7	0.5	-3

In this table, the numerical indicators are given according to the section number of the transmission line.

We will enter these values in the window of visualization of a fuzzy logical conclusion already created in advance.

As a result, we obtain the data listed in table 3.

Table 3 - The results of fuzzy inference

section of the transmission line	Degree of belonging of the fault level "high"
1.1	0.5
1.2	0.87
1.3	0.83
1.4	0.87
1.5	0.5
1.6	0.9
1.7	0.6
2.1	0.83
2.2	0.82
2.3	0.828
2.4	0.6
2.5	0.6
2.6	0.55
3.1	0.82
3.2	0.86
3.3	0.812
3.4	0.85
3.5	0.836
3.6	0.9
3.7	0.855
3.8	0.836

From the obtained results it can be concluded that if there is a signal of damage to the transmission line, and often triggers protection equipment that indicates which line is damaged, then entering data from the meteorological center, you can determine approximately where it happened.

In this case, we see that the most likely malfunction occurred on L1: section 1.6, with a slightly smaller possibility on sections 1.2 and 1.4; on L2: 2.1, with a slightly smaller possibility on 2.3 and 2.2; on L3: 3.6, with a slightly lower possibility on 3.2 and 3.7. These data can serve as a basis for development of a route of movement of operatively - exit crew on the principle "from a site with the greatest to a site with less risk of occurrence of damages".

V. CONCLUSIONS

In the course of the work was:

1. An analysis of modern methods and tools for detecting damage to the power supply network.
2. A method for determining the location of damage has been developed and researched, which uses additional information in the form of readings recorded by devices installed at substations in order to increase the probability of successful determination of the location of damage.

And also conclusions are made:

1. The system provides additional information on the location of damage to power lines, as well as allows you to determine the optimal route of the operational and exit team, which reduces the time of search for damage and, consequently, the shortfall of electricity to consumers.
2. The system is open to changes and improvements by changing the membership functions for input and output variables, editing the rules of fuzzy inference, as well as introducing informal knowledge of experts, dispatchers working on this transmission line.
3. The system for determining the damage to the power supply network, modeled in the MatLab program, is ready and easy to use.
4. The use of fuzzy logic does not offer to completely abandon the use of expensive tools to determine the location of damage, but allows you to improve and speed up the search process without much expense.

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DETERMINATION OF INTERVALS OF DISCRETIZATION OF TIME SERIES OF MEASUREMENTS OF TECHNOLOGICAL PROCESS PARAMETERS IN ASK TP

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Abstract. *At the current stage of development of the rural economy of our country, its products are not fully competitive. One of the reasons for this is the high cost of production. Automation of agricultural production increases the reliability and extends the service life of equipment, facilitates and improves working conditions, improves labor safety, reduces the use of labor and economic costs, and increases the quantity and quality of products.*

Therefore, the improvement of the existing methods of obtaining information for the purposes of management by substantiationdetermination of sampling intervalstime series of technological process parameter measurements is an important and urgent task.

The goal of the work*. The purpose of this work is to increase the efficiency of automation systems by technological processes based on the use of modern computer technologies.*

General characteristics of work. *A comparative evaluation of the effectiveness of using known techniques for determining the discretization interval of a time series of technological process parameter measurements in automation systems was performed.A new method for determining the sampling interval for automation systems is proposed, which is based on the use of the discrete Fourier transform for a smoothed digital signal and filtered noise and the Kotelnikov calculation theorem. Obtained calculation formulas.*

Key words: *measurement channel, Kotelnikov's theorem, Fourier transform, sampling interval, numerical filtering.*

I. INTRODUCTION

Any reasonable type of human activity is based on information about the properties of the state and behavior of that part of the real world with which this activity is connected.

Information in the technical system arises in the process of production and management. In management, information plays a decisive role, developing and changing under the influence of economic factors, scientific and technological progress, the external environment, production needs, and the organization of the management process.

When using information, a very important characteristic is its adequacy, which means the degree of correspondence of the image created with the help of the received information to a real object, process, phenomenon. In technical systems, the correctness of decision-making depends on the degree of adequacy of information.

In the production process, unacceptable deviations of technological parameters from the specified (normal) values may occur, caused by various reasons. Manufacturing facilities that provide the technological process cannot always eliminate these deviations on their own. Therefore, they are equipped with appropriate control automation systems, which ensure the normal flow of the technological process.

Automation of various types of production is an important direction of scientific and technical development of society. It ensures an increase in labor productivity, the release of a person from the production process, and an increase in the quality of products [1].

Therefore, the improvement of the existing methods of obtaining information through justificationdetermination of sampling intervalstime series of measurements of technological process parameters in ASK TP is an important and urgent task.

II. THEORETICAL BASICS

2.1. Measurementtechnological parameters in ASK TP

The measurement of technological parameters in the ASK TP is implemented with the help of measuring channels.

The measuring channel is a structurally or functionally separated part of the information system, which performs a sequence of operations from the perception of the measured quantity to obtaining the result of its measurements, which is displayed by a number or a code corresponding to it.

A typical structure of the measuring channel is presented in fig. 1 [2, 3].

Fig. 1. Typical structure of the measuring channel

Here $x(t)$ - measured parameter a $y(t)$ - measurement information signal.

Primary transducers (sensors) are measuring devices that perceive the controlled parameter and convert it into a signal (usually electrical) suitable for transmission over communication channels, further conversion, processing and storage, which is not directly perceptible by the observer.

If the sensor signal parameters do not agree with the analog-to-digital converter (ADC) input parameters or do not meet the standard (for example, the ADC input is a

voltage in the range $0 \div 10$ В, and the sensor (thermocouple) has an output voltage in the range from 0 to 100 mV), then a normalizing converter is used, which provides normalization of the sensor signal (bringing it to unified change ranges), galvanic isolation of the output circuits of the primary converters and the input circuits of the input module the controller.

A unified signal is a signal of remote transmission of information with unified parameters that provides an interface between units, devices and installations.

Unified values of the measuring signal at the ADC input $z(t)$ with the linear static characteristic of the normalizing converter are determined by the ratio [4]:

$$y_{\text{ун}}(t) = \frac{y(t)(Y_{\text{ун,max}} - Y_{\text{ун,min}}) + Y_{\text{ун,min}} y_{\max} - Y_{\text{ун,max}} y_{\min}}{y_{\max} - y_{\min}},$$

where: $y(t)$ - current value of the measuring signal; $Y_{\text{ун,min}}$, $Y_{\text{ун,max}}$ - the minimum and maximum value of the unified signal; $y_{\min}$, $y_{\max}$ - the minimum and maximum value of the measuring signal.

The structure of the measuring channel is determined by the measuring task it implements and the general methodology of building the system. In general, the measuring and informational parts can be distinguished in the channel. The measuring part includes: primary measuring transducer, normalizing transducers, switches. All elements of the measuring part have standardized metrological characteristics, and directly affect the total error of the channel. The information part includes ADCs, databases, software components, etc. Measurement information in the information part of the channel is presented in digital form [2, 3, 4].

The components of the measuring part are included in the signal $y(t)$ a certain fallibility $\varepsilon(t)$.

Signals of measurement channels of technological parameters are functions of time $z = f(t)$. Polling period of sensors of analog variables Δt depends on the dynamic characteristics of the signal and the measuring channel. This problem is solved taking into account two contradictory considerations. Magnification Δt, on the one hand, reduces the load on the processor, and on the other hand, the error of determining the values increases $\overline{x}_i(i\Delta t)$.

2.2. Existing methods of determining the survey period of analog variables

Time discretization step Δt can be determined by the Kotelnikov calculation theorem (in the English-language literature - the Nyquist-Shannon theorem) [5], whichsays that the analog signal $z(t)$,whathas a limited frequency spectrum, can be unambiguously and losslessly restored in its own waycalculations, taken with the sampling frequency $f_{\text{д}}$, which should be at least twice the maximum frequency of the spectrum $f_{\max}$:

$$f_{д} \geq 2 f_{\max} .$$

Then the value Δt it is necessary to choose no more than half a period of the maximum frequency of the spectrum $f_{\max}$

$$\Delta t \leq 1/(2 f_{\max}) .$$

Implementation length T at the same time is

$$T = (N-1)/f_{д} ,$$

and the frequency of the first harmonic is in hertz

$$f_1 = f_{д}/(N\text{-}1) .$$

However, the subtraction theorem is applicable to the case where the signal started infinitely long ago and never ends, and has no breakpoints. Real signals do not meet these conditions because they are finite in time and usually have discontinuities in time realization. Accordingly, the width of their spectrum is infinite. In this case, full recovery of the signal is impossible [6, 7].

Therefore, in each specific case, it is necessary to find a compromise solution based on the nature of the signal, the required accuracy of its restoration, the characteristics of the applied smoothing filter, and other factors. All this leads to the fact that in real automation systems, the sampling frequency is empirically selected in k times higher than the frequency $2 f_{\max}$:

$$f_{д} = k \cdot 2 f_{\max} /$$

Values are usually used k in the range of 2-5, but clear criteria for determining the value k currently does not exist for a specific time series in literary sources.Given that the time series of real technological parameters have the maximum frequency of the spectrum $f_{\max} \leq 0{,}5$ Hz,value Δt with this approach varies within 0.04-0.5 s, and the number of counts per period of maximum frequency within 2-250 [2, 6].

Determination of the acceptable value of the sensor polling interval is also based on the following considerations.

Sinceelements of the information and measurement channel have inertia, which is characterizedconstant time T, theyislow-frequency signal filters.going outfrom this, inmeasuring channelsthe element with the maximum value is selectedconstant timeand,reducingher at $5 \div 10$time,determinethe assumed value of the polling period of the sensors from the ratio $\Delta t \leq T_{\max} / (5 \div 10)$ [2, 3].

Determination of the value of the acceptable period of survey of the sensors is also carried out on the basis of the autocorrelation function $R_{\bar{x}}(\tau)$ [7] (Fig. 2).

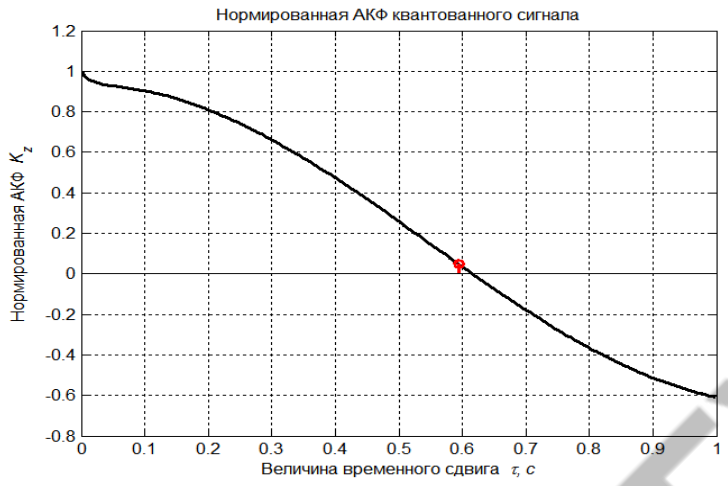

Fig. 2. Normalized autocorrelation function of the measurement signal

For a number series $\overline{x}_1, \overline{x}_2, \ldots, \overline{x}_n$ with known mathematical expectations $M_{\overline{x}}$ and dispersion $D_{\overline{x}}$ the autocorrelation function is defined by the formula

$$R_{\overline{x}}(k) = \frac{1}{(N-1)D_{\overline{x}}} \sum_{i=1}^{N-k} (\overline{x}_i - M_{\overline{x}})(\overline{x}_{i+k} - M_{\overline{x}})$$

To define Δt in this case, the ratio is used

$$\Delta t \le 4\tau_{cn} D_{\overline{x}-x} / D_x$$

where τ_{cn} is the decay time of the autocorrelation function, that is, the time it takes for the autocorrelation function to reach its values $R_{\overline{x}}(\tau_{cn}) \le 0{,}05 R_{\overline{x}}(0)$; $D_{\overline{x}-x}$ - dispersion of measurement error; D_x - dispersion of the measured signal.

Minimum value τ_{cn} is determined by the implementation of a random process (Fig. 3) according to the formula:

$$\tau_{cn,\min} = \tau_p / N_{\text{пер}}$$

where $N_{\text{пер}}$ – the number of crossings by the signal of the line of mathematical expectation in the time interval τ_p; τ_p is the duration of the implementation of the random process, which is chosen so that $N_{\text{пер}} \ge 100$ [2, 4].

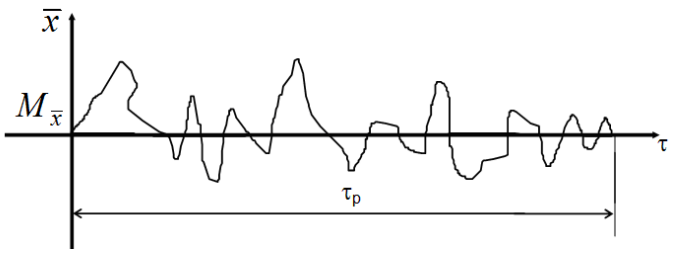

Fig. 3. Implementation of the measuring signal

III. JUSTIFICATION OF THE DETERMINATION OF DISCRETIZATION INTERVALS OF THE TIME SERIES OF THE MEASUREMENTS OF THE TECHNOLOGICAL PROCESS PARAMETERS

3.1. Definition of a mathematical apparatus

All of the above approaches to determining the sensor polling interval are not unambiguous. Therefore, the development of a more comprehensive approach is an urgent task.

Signal i-th dimension $z_i(t)$ is comingin the corresponding controller modules, where it is converted into digital form. However, the information obtained in this way is not suitable for use in control tasks due to the presence of interference, and therefore it is necessary to perform its preliminary processing, which is called primary.

The list of stages of this processing is determined by the sequence of transformations that the measurement information signal undergoes in the ADC, a typical algorithm of which is presented in Fig. 4 (see appendix) [3, 9].

Most signals in automation systems are analog in nature. They change continuously over time and can take any values within a certain range. It is impossible to enter such a signal into a computer and process it, because it has an infinite number of values at any time interval. Therefore, in digital processing systems, the signal is presented in discrete digital form.

A digital signal can be obtained from an analog signal by time sampling, level quantization, and encoding. The values of a digital signal are called counts.

In practice, the method of representing a signal by a sequence in which readings are located at equal time intervals has become widespread Δt.

In this case, the signal is determined by the sequence of its values $z(0), z(\Delta t), z(2\Delta t), \ldots$. This sequence is called a discrete sequence $z_i(i\Delta t)$.

Interval Δt called the sampling period, or the sampling interval. The inverse of the sampling period is called the sampling frequency, or the sampling frequency $f_д$.

The conversion of an analog signal into a discrete sequence of values is called time sampling.

It is obvious that the representation of the signal by a discrete sequence of readings leads to the loss of information about the behavior of the signal in the intervals between readings. To minimize these losses, the sampling period Δt must be reduced. However, reducing the discreteness period leads to an increase in the number of deductions and, as a result, to an increase in the volume of calculations. Therefore, when choosing a discretization period, you have to look for a compromise solution.

Operations of time discretization and level quantization are performed in ADC analog-to-digital converters. Elements of a digital sequence $z_ц(i)$ can take only a number

of discrete values $z_{ц,1}, z_{ц,2}, \ldots, z_{ц,N-1}$, the number of which depends on the number of digits used.

Thus, signal quantization is associated with the occurrence of an additional error.

To determine the sampling intervals of the measurement signal, we will use its frequency representation.

The frequency representation can be obtained by using the methods of harmonic analysis - a section of mathematical analysis in which the properties of periodic non-sinusoidal functions are studied using their representation in the form of Fourier series or integrals [7, 8].

In practical applications, we deal with finite samples of values. For the purposes of spectral analysis of a discrete signal, the continuous Fourier transform cannot be used, since it is intended for continuous signals. In this case, the discrete Fourier transform of the DFT is used.

The DFT is performed on the finite sequence N of calculations or over a periodic sequence in which the period consists of N calculations Assume that the signal is sampled at equal time intervals Δt, and as a result, a finite discrete sequence is obtained:

$$z_i = z(i\Delta t) = z(0), z(\Delta t), z(2\Delta t), \ldots, z[(N-1)\Delta t], i = 0,1,\ldots,N-1.$$

DFT sequence $z(i\Delta t)$ is defined as a discrete sequence Z_k from N calculations in the frequency domain:

$$Z_k = Z(kf_1) = Z(0), Z(\mathrm{f}_1), Z(2f_1), \ldots, Z[(N-1)f_1], k = 0,1,\ldots,N-1,$$

where f_1 - the frequency of the first harmonic, which is calculated from the expression

$$f_1 = 1/[(N-1)\Delta t].$$

Sequence Z_k in trigonometric form is determined by the ratio:

$$Z_k = \frac{1}{N-1}\sum_{i=0}^{N-1} z_i e^{-jk\frac{2\pi}{N-1}i} = \frac{1}{N-1}\sum_{i=0}^{N-1} z_i \left[\cos\frac{k2\pi i}{N-1} - j\sin\frac{k2\pi i}{N-1}\right].$$

According to the last relation, the meaning of the DPF is that the original non-periodic function of an arbitrary shape is represented as a set of sines or cosines with different frequency and amplitude. In other words, a complex function will turn into many simpler ones.

Each sinusoid (or cosine) with a certain frequency and amplitude obtained as a result of the DFT is called a spectral component or harmonic. The spectral components form the Fourier spectrum.

Visually, the Fourier spectrum is presented in the form of a graph on which the frequency is plotted along the horizontal axis f, and vertically – the amplitude of the spectral components (Fig. 5).

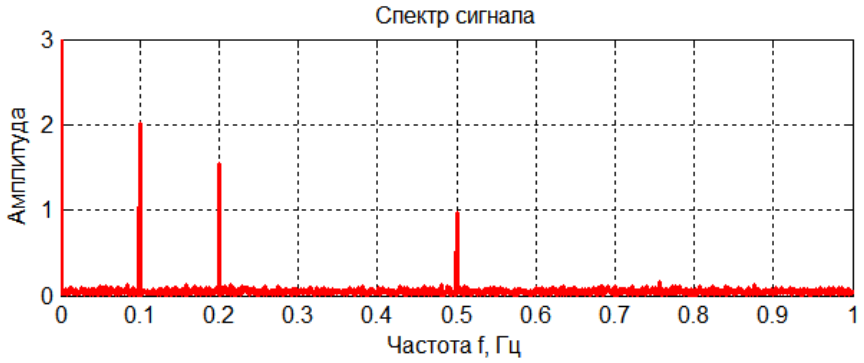

Fig. 5. Frequency spectrum of the signal

Then each spectral component can be represented as a reference, the horizontal position of which corresponds to its frequency, and the height to its amplitude. A harmonic with zero frequency is called a constant component (in time representation it is a straight line).

The spectrum of the DFT signal in practice is determined only for positive frequencies in the range from 0 to $f_д$.

Frequency $f_н = f_д/2$ received the name Nyquist frequency. Nyquist's higher frequency components are a mirror image of the lower frequencies.

Therefore, when analyzing signals, it is advisable to analyze the spectrum only in the range from 0 to $f_н$, by increasing the modules of the DPF bins by 2 times.

For the correct use of DPF, the following two important features should always be remembered:

- to expand the band of spectral analysis, you need to increase $f_д$, i.e. take time-based bills more often;

- in order to improve the frequency resolution without changing the bandwidth of the spectral analysis, it is necessary to increase N, that is, to analyze a longer sample of the signal.

There is no single correct spectrum of any signal. The DFT decomposes the signal not into the harmonics of the signal, but into its own harmonics.

Strictly speaking, the decomposition result cannot be interpreted as a signal spectrum. Decomposition is simply data, applied to which the inverse transformation can be applied to obtain an output signal. However, with a sufficiently small value of the frequency spectrum discretization step, the spectrum graph displays the frequencies of the output signal adequately.

To ensure functioning on a real-time scale, the full calculation of the DFT must be performed in the time interval corresponding to the accumulation of one data packet. It is assumed that while the DFT calculation of the current data packet is being performed, the PLC processor is accumulating data for the next packet.

3.2. Definition of the filtering operation algorithm

When defining the time step of discretization Δt the filtering operation that is should also be taken into accountis the most complex of the operations of primary signal processing of measurement information, and its efficiency is determined by the value Δt .

In general, filtering can be performed in hardware using RC or LC filters before feeding the signal to the controller, or in software using various filtering algorithms. Exponential smoothing algorithms have become the most widely used in ASK TP (about 90% of filtering tasks are solved with the help of these algorithms) [2, 9].

Algorithms of exponential smoothing belong to the class of adaptive smoothing methods, the main characteristic of which is the ability to continuously take into account the evolution of the dynamic characteristics of the measured parameter, adjust to this dynamic, giving, in particular, the greater weight and the higher the information value to the measurements that are closer to the current moment in time. They allow you to update the smoothing results with minimal delay and with the help of relatively simple mathematical procedures. The advantages of exponential filtering algorithms include the low complexity of calculations and the small amount of controller memory required for data storage.

Two such algorithms are usually used in PLCs - the algorithm of simple exponential smoothing, which is used in the absence of a certain tendency of changes in indicators (the so-called trend) in the time series of measurements, i.e. for stationary or quasi-stationary time series, and the Holt algorithm in the presence of a trend (non-stationary time rows).

The simple exponential smoothing algorithm (Brown's method) is defined by the recurrence relation of the following form

$$\hat{z}_i = \hat{z}_{i-1} + \alpha\left(z_{i-1} - \hat{z}_{i-1}\right),$$

where $\hat{z}_i$ and $\hat{z}_{i-1}$ – current and previous value of the smoothed signal; z_{i-1} - previous value of the measured signal; α is the smoothing coefficient, which is chosen a priori ($0 < \alpha < 1$).

Thus, the current value of the smoothed signal is determined as the sum of the previous smoothed value and corrections for the error of the previous value of the signal measurement. The weight of the correction determines how "sharply" the algorithm will react to changes.

The closer the value α to 1, the more the influence of the last measurement values is taken into account. If α closer to 0, the weights by which the measurement values are weighted decrease slowly, that is, a larger number of previous measurements are taken into account.

Of course the value α is within $0{,}05 \div 0{,}3$. A value of 0.5 is almost never exceeded.

It is recommended to set a value for a slowly changing time series α in the range $0{,}05 \div 0{,}2$, and for rapidly changing - in the range $0{,}3 \div 0{,}5$.

Simple exponential smoothing of time series containing a trend leads to a systematic error associated with the lag of the smoothed values from the actual levels of the time series.

To take into account the linear trend in non-stationary series, a special two-parameter exponential smoothing using the Holt method is used). If there is an upward or downward trend in the time series, then along with the assessment of the current level, an assessment of the slope is also necessary. In the Holt method, both the time series and the trend are simultaneously smoothed using two different parameters.

The two-parameter smoothing method includes two equations. The first is intended for smoothing a series of measured values, and the second - for smoothing the trend

$$\hat{z}_i = \alpha_1 z_i + (1-\alpha_1)(\hat{z}_{i-1} + T_{i-1})$$
$$T_i = \alpha_2(\hat{z}_i - \hat{z}_{i-1}) + (1-\alpha_2)T_{i-1},$$

where $\hat{z}_i$ and $\hat{z}_{i-1}$ - current and previous value of the smoothed signal; z_i - current value of the measured signal; T_i and T_{i-1} - current and previous value of the trend; α_1 and α_2 – time series and trend smoothing coefficients, the values of which are selected a priori in the range $0 \div 1$.

The adequacy of the smoothed time series can be most easily determined by calculating the average relative error of approximation [8, 9]:

$$\bar{\Delta}_{\text{ап}} = \frac{100 \cdot N}{\sum_{i=1}^{N} z_i} \sqrt{\frac{\sum_{i=1}^{N} (z_i - \hat{z}_i)^2}{N}},$$

where N - the number of measurement points stored in the PLC memory.

Approximation error within $5 \div 7\,\%$ indicates a good fit of the model to the original data. Permissible limit of values $\bar{\Delta}_{\text{ап}}$ - not more $8 \div 10\,\%$ (sometimes up to 15 %).

3.3. The essence of the developed methodology

The technique is based on the simultaneous use of DFT for a smoothed digital signal and filtered noise.

To determine the time step of the discretization Δt is suggested by comparing the harmonic amplitudesmaximum spectrum frequency $f_{\max}$ choose the optimal value in different components of the signaldiscretization step Δt for a specific measured parameter.

Considering the standard accuracy of automatic control systems, it can be assumed that the share of this amplitude in the filtered noise $A_{\max,\text{шум}}$ should be no more than 5% of the amplitude of the smoothed signal $A_{\max,\text{згл}}$, i.e $100\,A_{\max,\text{шум}} / A_{\max,\text{згл}} \le 5\ \%$.

IV. PRACTICAL IMPLEMENTATION OF THE METHODOLOGY

To test the proposed approach and compare it with known approaches, a simulation model of the measuring channel and ADC was developed using the Matlab program (appendix).

Temporal number accurate measurementsparameterwas formed from 3 harmonicsonformula

$$y(t) = y_0 + a_1 \sin(2\pi f_1 t) + a_2 \sin(2\pi f_2 t) + a_3 \sin(2\pi f_3 t)$$

where a_1, a_2, a_3, $pa\partial/c$ and f_1, f_2, f_3, Hz - amplitudes and frequencies of harmonics that are randomare determined from acceptable lists of values $0,8 \div 1,9$ and $0.05 \div 0.5$ Hz.

The measurement information signal at the input of the ADC was formed according to the formula $z(t) = y_{ун}(t) + \varepsilon(t)$ where $\varepsilon(t)$ - the error of the measuring channel, distributed according to the normal law of probability distribution. Noise filtering was performed using a simple exponential smoothing method.

The frequency representation of the signals of the measuring channel is shown in Fig. 6 (see appendix).

Dependencies of the fate of amplitudes of signal harmonics in noise fromvaluesdiscretization step Δt for different harmonics are shown in fig. 7.

The processing of the obtained results made it possible to obtain a formula for an unambiguous and reasonable determination of the step size Δt by known value $f_{\max}$ (Fig. 8, and see the appendix)

$$\Delta t = 0,0045 + 0,138 \cdot e^{-17,14 f_{\max}},$$

or the formula for determining the coefficient k for Kotelnikov's theorem in the form of notation $f_д = k \cdot 2 f_{\max}$ (Fig. 8, b, see the appendix)

$$k = 208,3\left(1 + 0,33 \cdot e^{-125 f_{\max}} - 1,33 \cdot e^{-31,25 f_{\max}}\right),$$

which corresponds to the specified error of 5% (with other values of the specified error, similar dependencies can be obtained)

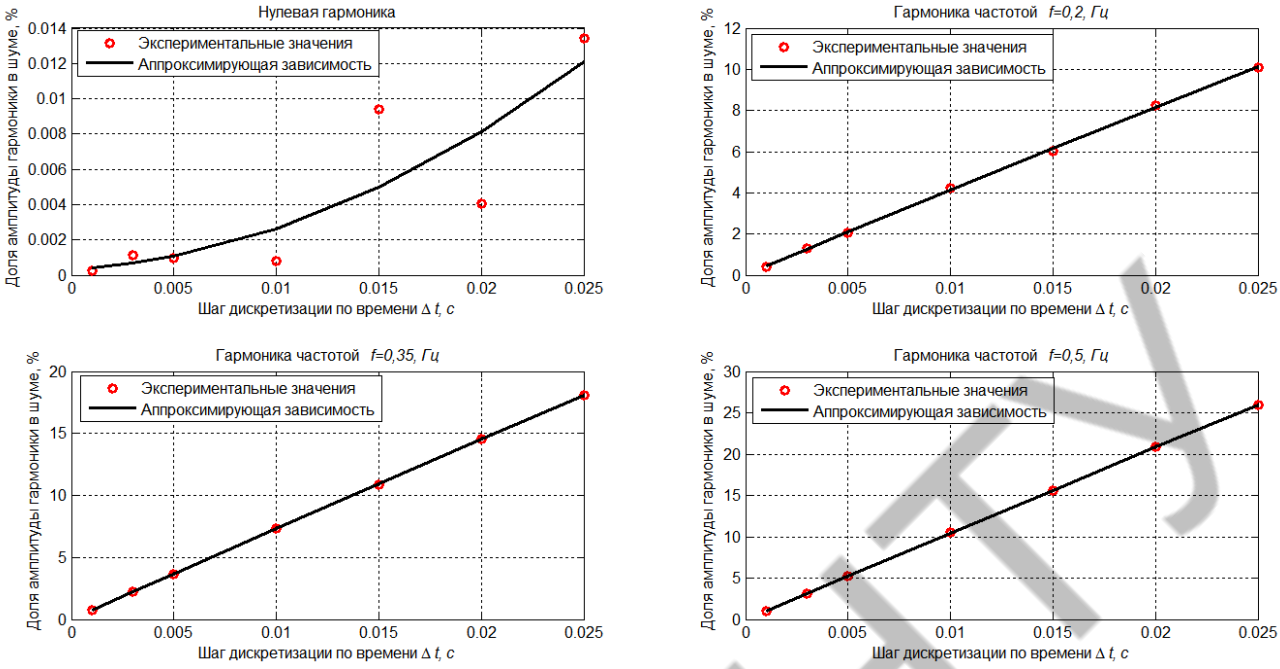

Fig. 7. Dependencies of the fate of amplitudes of signal harmonics in noisefroma step Δt

The analysis of the obtained results shows that the value Δt at $f_{\max} = 0,05 \div 0,5$ Hzvaries depending on $f_{\max}$ within 0.005-0.063 s, and the number of counts per period of maximum frequency - within 300-406.

The obtained results can be used to measure any real parameter and differ significantly from the recommendations of known approaches.

Therefore, to compare the accuracy of restoration of the discretized signal, it was established that at the maximum value $\Delta t = 0,1$ c, which is determined by Kotelnikov's theorem, harmonics with frequencies of 0.1, 0.2, 0.3, 0.4, and 0.5 Hz are distinguished with errors of 20.6, 41, 63, 83, and 100%, respectively. At the minimum value $\Delta t = 0,04$ c, which is determined by Kotelnikov's theorem, these same harmonics are distinguished with errors of 8.3, 16.7, 25, 33.4, and 41.8%, respectively, which is unacceptable.

To evaluate the effectiveness of the filtering operation, a dependency was also determinedaverage relative error of approximation $\bar{\Delta}_{\text{ап}} = f(\Delta t)$, where Δt were calculated according to formula (1) (Fig. 9).

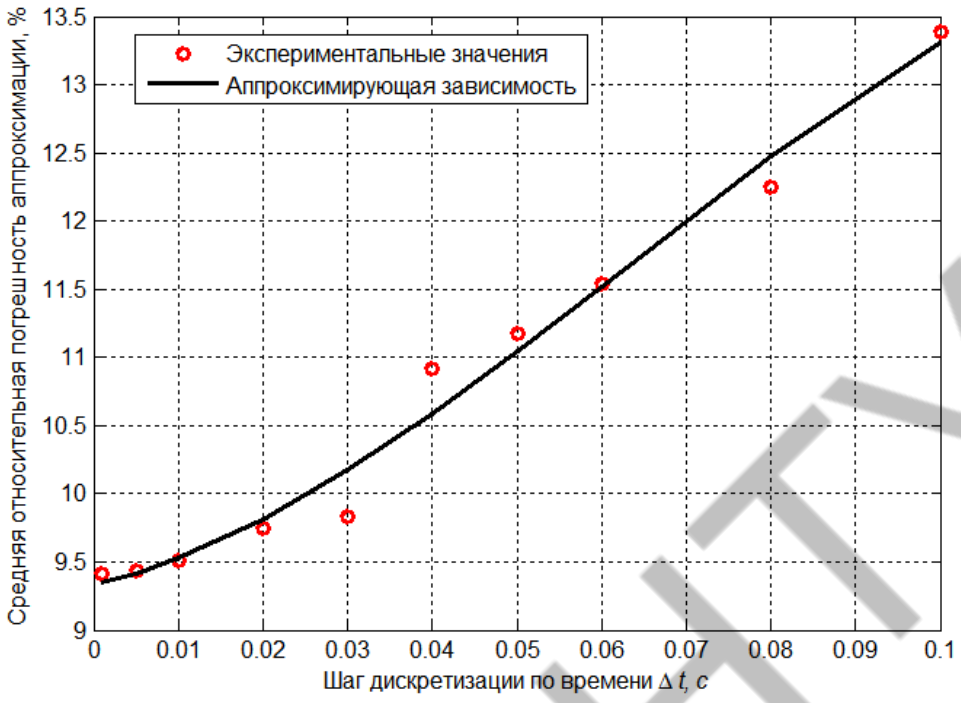

Fig. 9. Dependencyaverage relative filtering error fromdiscretization step Δt

In the case of using the autocorrelation function of the signal, a significant ambiguity in the selection of the value was found Δt with this approach (Fig. 10) and a significant overestimation of its values.

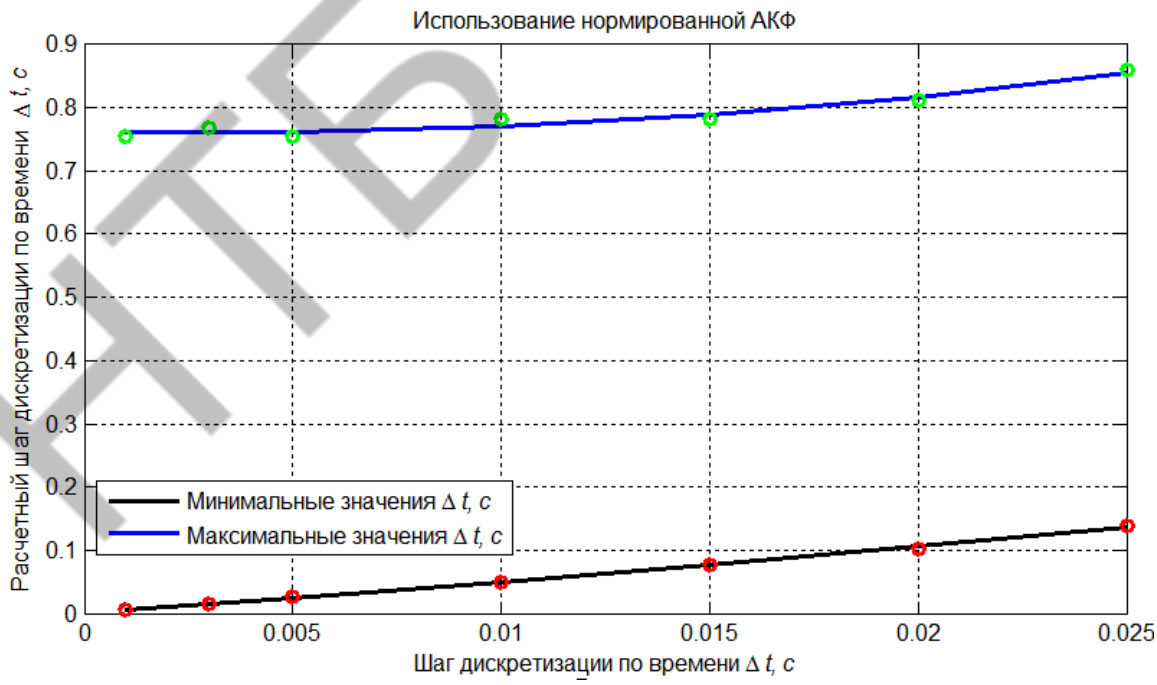

Fig.10. Definition of the sampling step Δt by the autocorrelation function

V. CONCLUSIONS

A new technique for determining the discretization interval of a time series of parameter measurements for automation systems has been developed, which is based on the use of discrete Fourier transformation for a smoothed digital signal and filtered noise and the Kotelnikov calculation theorem.

The use of the proposed method allows you to ensure the necessary accuracy of obtaining measurement information for any real parameter of the technological process and reasonably formulate the requirements for the used controller and measurement tools.

In addition, the proposed technique can be used to select the parameters of smoothing digital filters, as well as for a comparative analysis of their effectiveness.

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ADDITION

The program of the simulation model of conducting experiments

```
close all;clear all;clc
% ЗАДАНИЕ ИСХОДНЫХ ПАРАМЕТРОВ РАСЧЕТА
Tanaliz=600;% Длительность интервала анализа сигнала, с
dt=0.04;% Шаг дискретизации по времени, с
N_d=1200;% Постоянная составляющая измеряемого параметра
skoSUM=1.5;% Ср. кв. отклонение шума
f=[0.3,0.4,0.5];a=(N_d*pi/30)*[0.025,0.03,0.015]; % Параметры зависимости w(t)
k_br=0.08;% Коэффициент передачи тахогенератора (первичный преобразователь)
yUmin=4;yUmax=20;% Диапазон изменения унифицированного сигнала y_ун(t), мА
n=10;% Количество двоичных разрядов АЦП
% РАСЧЕТ
t=0:dt:Tanaliz;N=length(t);% Вектор отсчетов времени
p=[3,1,2];
%p=randperm(3) % Вектор случайной выборки параметров w(t)
%p=input('Введите вектор виборки параметров w(t) в формате [p1,p2,p3] -')
% Задание зависимости w=f(t)
Ag=[a(p(1)), a(p(2)), a(p(3))];
Us_d=N_d*pi/30;% Номинальная угловая скорость вращения ЭД
x=Us_d+Ag(1).*sin(2*pi*f(1)*t)+Ag(2).*sin(2*pi*f(2)*t)+Ag(3).*sin(2*pi*f(3)*t);
y=k_br*x;% Вектор измерительного сигнала y(t)
% НОРМАЛИЗАЦИЯ СИГНАЛА
% Вектор значений унифицированного сигнала y_ун(t)
y_max=max(y); y_min=min(y);Dy=0.5*(y_max-y_min);y_max=y_max+Dy; y_min=y_min-Dy;
yUn=(y*(yUmax-yUmin)+yUmin*y_max-yUmax*y_min)/(y_max-y_min);
% ДОБАВЛЕНИЕ ШУМА
% Вектор значений шума на входе АЦП
SUM=skoSUM*((y_max-y_min-2*Dy)/2)*randn(1,N);% Нормальный закон распределения
%k=1;SUM=k*(-skoSUM+2*skoSUM.*rand(1,N));% Равномерный закон распределения
z=yUn+SUM;% Вектор сигнала на входе АЦП z(t)
% КВАНТОВАНИЕ ПО УРОВНЮ
Nkv=2^n;% Количество уровней квантования
Skv=(yUmax-yUmin)/Nkv;% Шаг квантования
Ukv=[yUmin:Skv:yUmax];% Вектор значений уровней квантования
for i=1:N
if z(i)<Ukv(1);z(i)=Ukv(1);end
if z(i)>Ukv(length(Ukv));z(i)=Ukv(length(Ukv));end
j=1;while z(i)>Ukv(j);j=j+1;end;Zkv(i)=Ukv(j);
if (Ukv(j)-z(i))>0.5*Skv;Zkv(i)=Ukv(j-1);end
end
% ФИЛЬТРАЦИЯ ШУМА
% Сглаживание методами Брауна 1, 2 порядка и методом Хольта
alfaB1=0.3;alfaB2=0.3;alfaH1=0.3;alfaH2=0.2; % Значения коэффициентов сглаживания
% Инициализация фильтров
sBr(1)=mean([Zkv(1),Zkv(2),Zkv(3),Zkv(4),Zkv(5)]);sBr2(1)=sBr(1);sH(1)=sBr(1);TH(1)=0;
```

```
% Реализация алгоритмов фильтров
for i=2:N
sBr(i)=sBr(i-1)+alfaB1*(Zkv(i-1)-sBr(i-1));
sBr2(i)=sBr2(i-1)+alfaB2*(sBr(i-1)-sBr2(i-1));
sH(i)=alfaH1*Zkv(i)+(1-alfaH1)*(sH(i-1)+TH(i-1));
TH(i)=alfaH2*(sH(i)-sH(i-1))+(1-alfaH2)*TH(i-1);
end
% Сглаживание методом скользящего среднего
sSS(1)=Zkv(1);sSS(2)=mean([Zkv(1),Zkv(2)]); sSS(3)=mean([Zkv(1),Zkv(2),Zkv(3)]);
sSS(4)=mean([Zkv(1),Zkv(2),Zkv(3),Zkv(4)]);
for i=5:N;sSS(i)=mean([Zkv(i),Zkv(i-1),Zkv(i-2),Zkv(i-3),Zkv(i-4)]);end
Zsgl=sBr;% Выбор метода фильтрации
% ОПРЕДЕЛЕНИЕ АВТОКОРРЕЛЯЦИОННОЙ ФУНКЦИИ СИГНАЛА
vs=mean(Zsgl); % Определение выборочного среднего
vd=cov(Zsgl);% Определение выборочной дисперсии
for k=0:round(1/dt)
su=0;for ik=1:N-k;su=su+(Zsgl(ik)-vs)*(Zsgl(ik+k)-vs);end
tau(1+k)=k*dt;AKF(1+k)=su/((N-1-k)*vd);end
ik=1;while AKF(ik)>0.05*AKF(1);ik=ik+1;end;
% ГАРМОНИЧЕСКИЙ АНАЛИЗ
fd=1/dt;% Частота дискретизации, Гц
fnaikv=fd/2;% Частота Найквиста, Гц
df=fd/(N-1);% Шаг дискретизации по частоте, Гц
Sign=[yUn;Zkv;Zsgl;Zsgl-Zkv];% Матрица анализируемых сигналов
for i=1:4
DPF(i,:)=abs(fft(Sign(i,:),N));% Амплитуды преобразования Фурье сигналов
DPF(i,:)= 2*DPF(i,:)./N; % Нормировка спектра по амплитуде
end
DPF(1:4,1)= DPF(1:4,1)./2; % Нормировка постоянной составляющей в спектре
f1=0:df:1*fnaikv;dv=length(f1);% Вектор частот отображения спектра
vs_A=mean(DPF(3,:));vsko_A= std(DPF(3,:));
j=1;for i=1:dv;if DPF(3,i)>(vs_A+1*vsko_A);Ng_F(j)=i;j=j+1;end;end
% РЕЗУЛЬТАТЫ РАСЧЕТА
format short g;
Rrasc(1)=Tanaliz;Rrasc(2)=dt;Rrasc(3)=N;Rrasc(4)=fd;Rrasc(5)=df;
Tanaliz_dt_N_fd_df=Rrasc
% Время спада автокорреляционной функции
sc=0;Z1=z- mean(z);for i=1:N-1;if sign(Z1(i)*Z1(i+1))<1;sc=sc+1;end;end
Tau_sp_min=Tanaliz/ sc
Tau_sp_max=tau(ik)
Cg_F=f1(Ng_F)% Частоты гармоник спектра полезной составляющей
Ag_0=(Us_d*k_br*(yUmax-yUmin)+yUmin*y_max-yUmax*y_min)/(y_max-y_min);
Ag=((Us_d+Ag)*k_br*(yUmax-yUmin)+yUmin*y_max-yUmax*y_min)/(y_max-y_min)-Ag_0;
TAg=[Ag_0,Ag] % Точные значения амплитуд спектра полезной составляющей
AGDPF=sprintf('Амплитуды гармоник спектра полезной составляющей по ДПФ сигналов [yUn;
Zkv; Zsgl; Zsgl-Zkv]')
Ag_F=[DPF(1:4,Ng_F)]
% ОПРЕДЕЛЕНИЕ АДЕКВАТНОСТИ АППРОКСИМАЦИИ
% Определение средней относительной погрешности аппроксимации
```

```
SOPA=100*(sqrt((sum((Zkv-Zsgl).^2))/N))/mean(Zkv)
% По времени спада автокорреляционной функции
dt_min=4*Tau_sp_min*cov(Zsgl-Zkv)/cov(z)
dt_max=4*Tau_sp_max*cov(Zsgl-Zkv)/cov(z)
SGSP=100*Ag_F (4,1:4)./Ag_F (3,1:4) % Содержание гармоник в шуме в % по ДПФ
%Sss=(SGSR(2)+SGSR(3)+SGSR(4))/3
% ВЫВОД ГРАФИКОВ
% График нормированной автокорреляционной функции Zkv (черный цвет)
plot(tau,AKF,'Color','k','LineWidth',2);hold all;grid on
stem(tau(ik),AKF(ik),'Color','r','LineWidth',2)
title('Нормированная АКФ квантованного сигнала');
xlabel('Величина временного сдвига  \it\tau, c'); ylabel('Нормированная АКФ \it  K_{z}');
It=700;% Количество точек вывода графиков
figure(2)
% График квантованного временного ряда, измеренного датчиком (зеленые точки)
plot(t(1:It),Zkv(1:It),'o','Color','g','LineWidth',2);hold all;grid on
% График точного изменения измеряемого параметра (черные точки)
plot(t(1:It),yUn(1:It),'o','Color','k','LineWidth',2)
% График сглаженного временного ряда (красный цвет)
plot(t(1:It),Zsgl(1:It),'Color','r','LineWidth',2.5)
title('Анализируемые временные ряды');
xlabel('Время \it  t (c)'); ylabel('Измеряемый параметр \it  z');
legend('Реальный ряд','Точный ряд','Отфильтрованный ряд')
figure(3)
% График спектра точного временного ряда (черный цвет)
subplot(2,2,1),plot(f1(1:dv),DPF(1,1:dv),'Color','k','LineWidth',2);grid on;
title('Спектр точного временного ряда');xlabel('Частота \it  f, Гц'); ylabel('Амплитуда');
% График спектра измеренного временного ряда (зеленый цвет)
subplot(2,2,2),plot(f1(1:dv),DPF(2,1:dv),'Color','g','LineWidth',2);grid on;
title('Спектр измеренного временного ряда');xlabel('Частота \it  f, Гц'); ylabel('Амплитуда');
% График спектра отфильтрованного временного ряда (синий цвет)
subplot(2,2,3),plot(f1(1:dv),DPF(3,1:dv),'Color','b','LineWidth',2);grid on;
title('Спектр отфильтрованного временного ряда');xlabel('Частота \it  f, Гц'); ylabel('Амплитуда');
% График спектра шума(красный цвет)
subplot(2,2,4),plot(f1(1:dv),DPF(4,1:dv),'Color','r','LineWidth',2);grid on;
title('Спектр отфильтрованного шума');xlabel('Частота \it  f, Гц'); ylabel('Амплитуда');
```

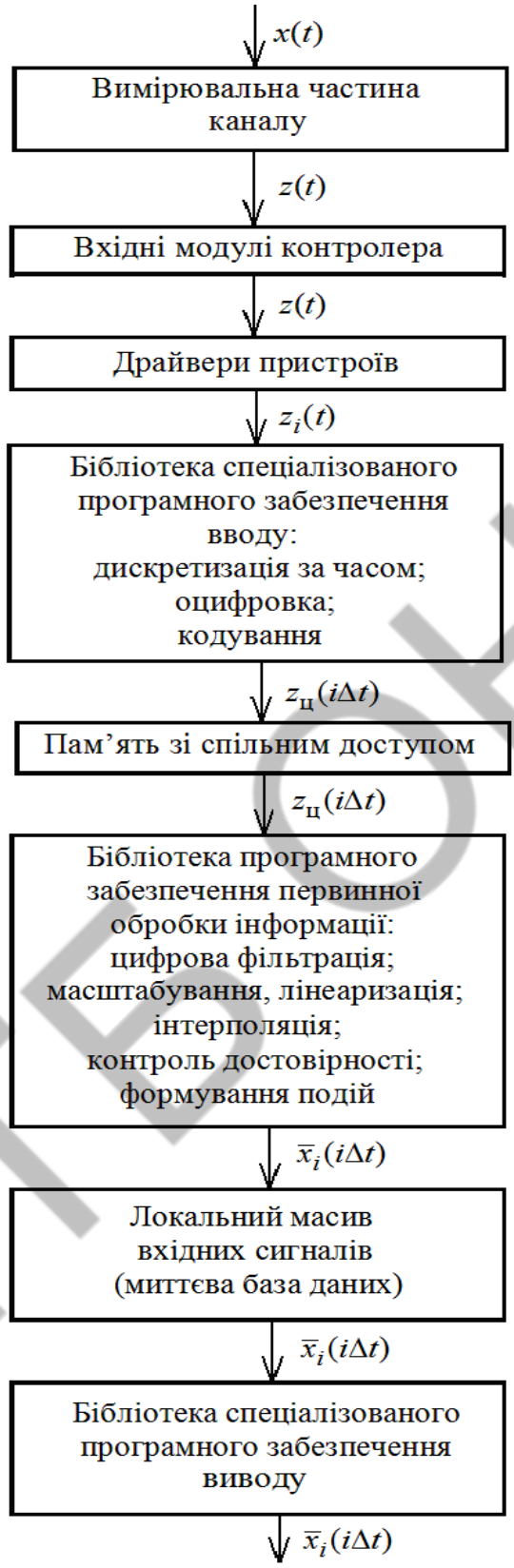


Fig.4. A typical algorithm for primary processing of measurement information

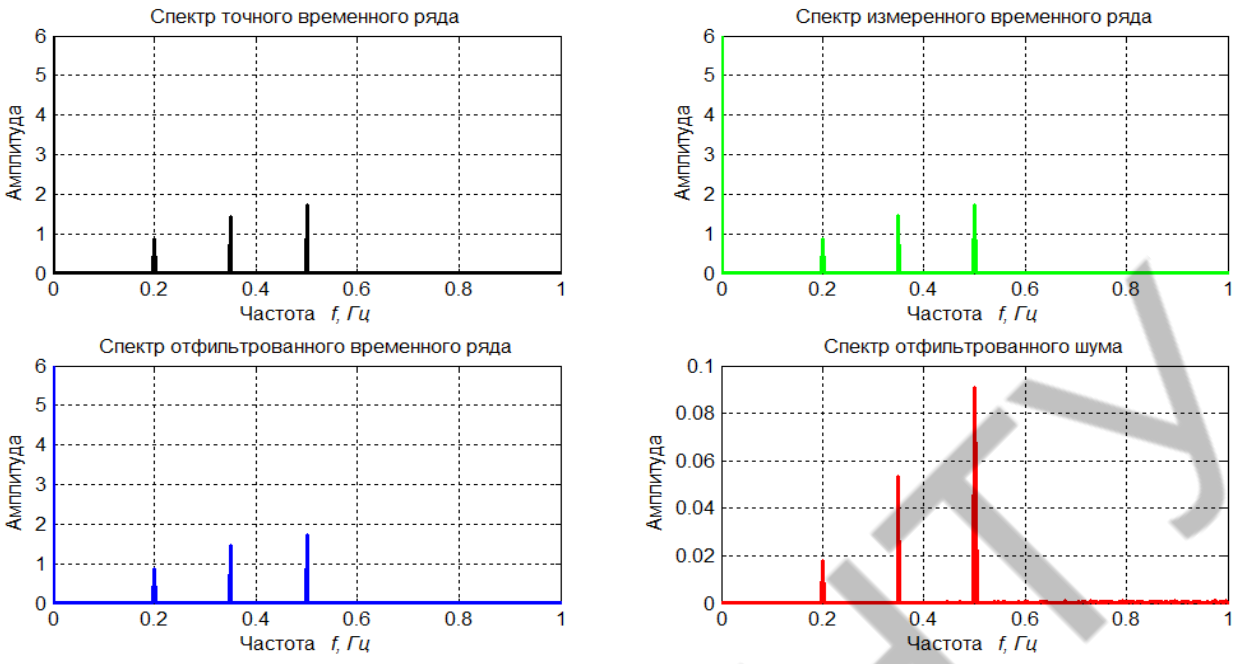
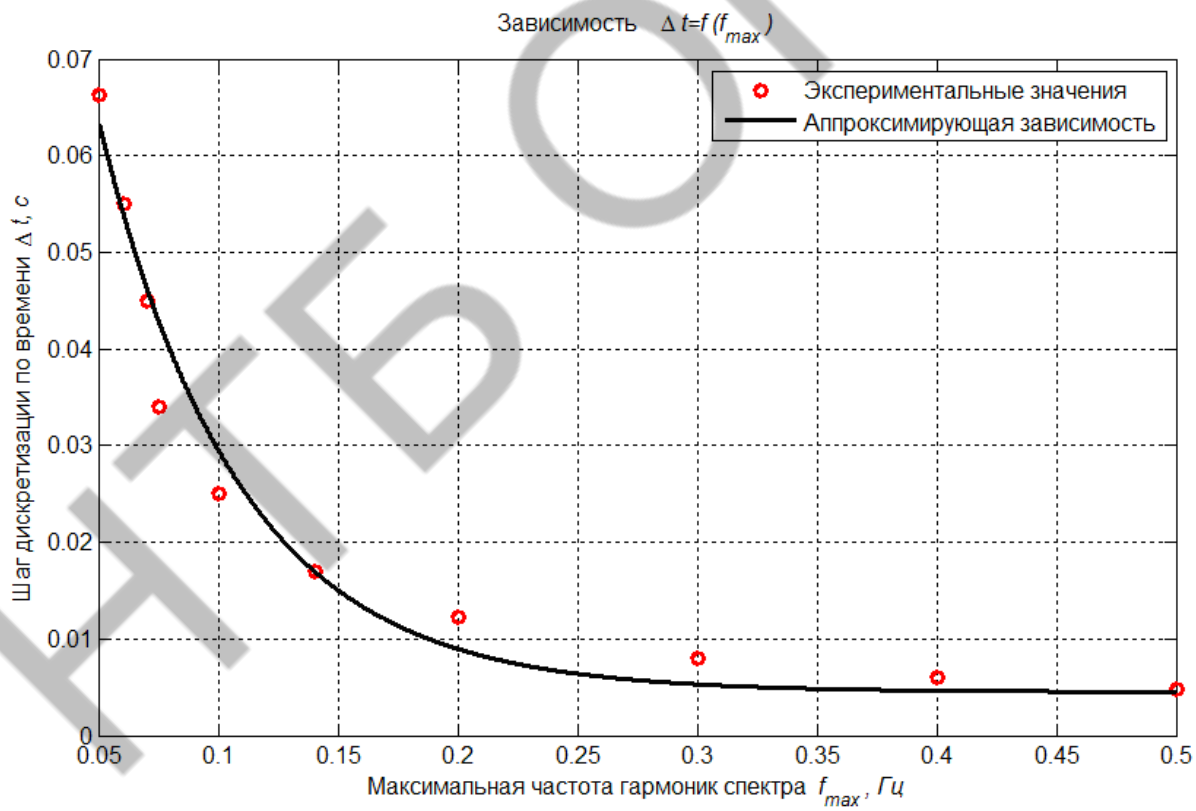
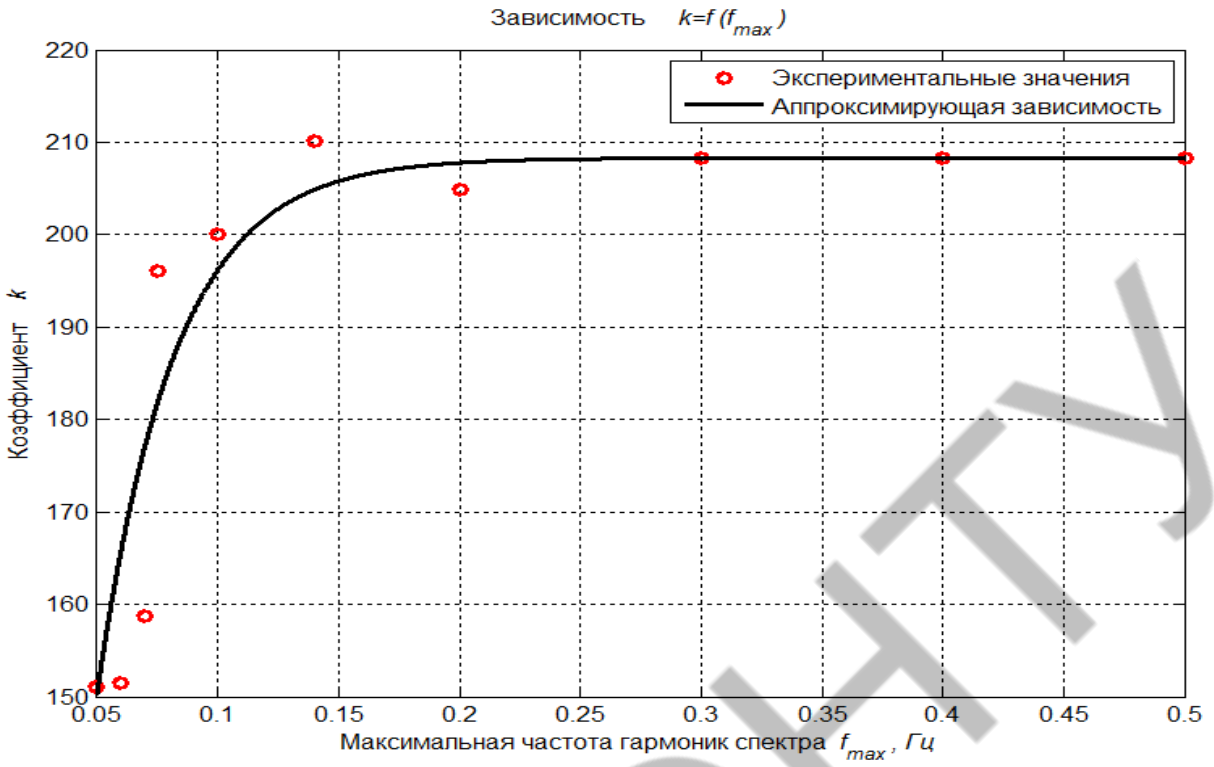


Fig. 6. Frequency spectra of signals



a)



b)

Fig.8. Results of computational experiments obtained with $100\,A_{\max,\text{шум}} / A_{\max,\text{згл}} = 5\ \%$

QUANTIFICATION OF A MECHATRONIC PNEUMATIC GRIPPING SYSTEM FOR A MULTI-LINK ROBOT MANIPULATOR

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Abstract. *The basis of the work is the tasks related to the synthesis of working bodies for moving artificial food, and the development of a control program for them based on PLC - namely, pneumatic grippers. An urgent task was also to ensure the movement of products processed by a robot manipulator according to the given law of movement. Based on the study of the dynamic characteristics of the drive and the control system of the power part of the position electro-pneumatic drive. Mathematical and computer modeling methods, methods of solving ordinary differential equations and partial differential equations, correlation analysis method are used. Analytical dependencies were obtained for controlling the drive of a robot-manipulator with a pneumatically controlled gripper to determine the kinematic parameters of the product movement during processing. The dynamic model of the pneumatic gripper and its drive was mathematically tested. The law of motion of the final link of the manipulator, close to the optimal speed, was obtained. On the basis of the research calculations and the analysis of the functional mechatronic modules, the energy efficiency of the proposed control scheme of the power part of the positional pneumatic drive was confirmed. The result of the study of the electropneumatic positional drive is presented in the form of an algorithm and a special program for calculating and comparing the kinematic and dynamic parameters of the drive.The technological time of the operation is adjustable and when using the exhaust cross-section of the working chambers of the pneumatic cylinder - 4 mm, the value of the working pressure up to 7 bar, the movement of the rod - up to 200 mm, it has optimal kinematic characteristics of work for a pneumatic gripper. The discrepancy between the value of the time of the working stroke of the output link of the functional mechatronic module calculated during the mathematical modeling after working out the kinematic cycle of the gripper was up to 3% for various input parameters.*

Key words*: functional, module, pneumatic gripper, electro-pneumatic drive, precision, variable gripper soft pads.*

I. INTRODUCTION

The complex process of optimal control of drives of technological equipment based on manipulator robots for food production has already been studied by many authors [1-4]. Therefore, modeling of the process of movement of artificial products by a gripper based on various mechatronic systems, taking into account the features of the design and real boundary conditions, dynamic processes in the pneumatic gripper - are relevant. After the implementation of existing technical decisions regarding the types of grippers in the technological equipment, robots-manipulators of packaging machines (PM) were chosen.

[5 -10]. In order to choose the law of operation of a pneumatic gripper and subsequent movement of an artificial product, one must first of all consider the possibility of practical implementation of such a law with a pneumatic drive. We considered the possibility of ensuring a smooth change of all technical parameters of the pneumatic gripper. [13] The criterion that characterizes the operations of moving an artificial product can be the law of motion, chosen on the basis of the quantification of the technical characteristics of the pneumatic gripper. [14-20] Therefore, the task of mathematical and physical modeling of the drive of a robot-manipulator is relevant**.**

II. LITURATURE ANALYSIS

The processes of food, chemical, textile, perfumery and many other industries are based on operations of metered supply of liquid products. For example, in work [1-20], the costs of the product, which are established by the technological regulations, are investigated. The authors describe a process control system based only on the contours of the automatic adjustment of one dosing parameter. The issues of development and implementation of aerial mechatronic dosing systems with tracking circuits for two or more technological parameters remain unresolved. Critical analysis of liquid food product dosing systems is based on electropneumatic systems and is complicated by the lack of ready-made industrial executive modules. In particular, in [2] dosing devices for small dose ranges. The analysis of the task of automating technological processes of aerial dosing, in work [3], describes the design of servo-pneumovalves. This description is even more complicated because the control object has an inertial delay and parametric non-stationarity. The results given in [4] can be a solution to overcome the relevant difficulties. In this case, a high-quality organization of dosing processes is possible only when closed systems of automatic regulation are used. Such tasks require the development of universal automatic dosing systems, which are functionally adapted to perform both batch and continuous dosing operations. [5,6] The text of the source [7-11] describes data on the dosing process with an analysis of the reliability parameters of technological elements. Pneumatic valves and product line connection systems are described, but the results are not complete. The dosing principle, described in [12], is time-oriented with the condition of ensuring a constant flow of liquid. Unfortunately, the results of the conducted experimental studies do not describe the energy consumption of the dosing system [13-17]. Therefore, there are reasons to assert the expediency of conducting a study devoted to the construction and testing of liquid product dosing systems based on electropneumatic complexes. And also, according to the method of empirical research, to obtain results for the analysis of the process of forming the dose of the product for the airlift dispenser system and the study of further dosing accuracy.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The object of research is the processes that take place in cyclic and positional electro-pneumatic drives of the robot manipulator and the associated pneumatic gripper.

The subject of the study is a self-developed design of a robot-manipulator with a gripping device with replaceable pads of contact surfaces.

The purpose of the study is to determine the optimal law of movement of the rod of the electropneumatic positional drive.

The purpose of the research is to expand the functional capabilities of food packaging equipment, it involves finding ways to improve pneumatic gripper drives in functional mechatronic modules of manipulator robots.

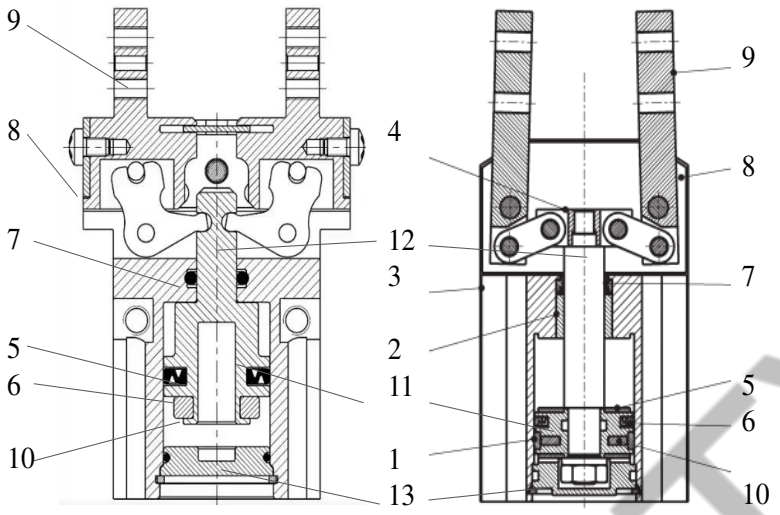
The materials and methods are formed on the basis of the quantification of the results of processing the dynamic characteristics of the drive and the control system together with the power part of the positional electropneumatic drive. Computer modeling and mathematical methods, methods of solving ordinary differential equations, correlation analysis method are used.

In order to obtain the results of the research of gripping pneumatic devices with different contact surfaces, the tasks were formulated:

- modeling of the law of motion of the pneumatic cylinder piston, as the basis of a pneumatic gripper with an initial air pressure drop close to the optimal speed of action. At the same time, two designs of grips and three designs of overlays on the gripping surfaces of the contact are considered.- research on the basis of a self-developed PLC control program (LAD language) and on the basis of experimental modeling of the operation of grippers of various designs, cases of smoothing of the acceleration function at the moment of disconnection of the driving force. The obtained results will make it possible to smoothly change the operating parameters of the manipulator robot: creation of a 3D model of a manipulator robot based on the general structural library of PARTcommunity CAD, taking into account the selection of drive elements for the construction of an experimental stand; a description of the method of selecting the initial stage of movement (by the x coordinate), taking into account the possible decrease in the performance of the executive mechanism; experimental study of the cyclic and positional electro-pneumatic drive for working out the modes of operation of various gripping modules in a packaging machine for artificial products with different surface geometries.

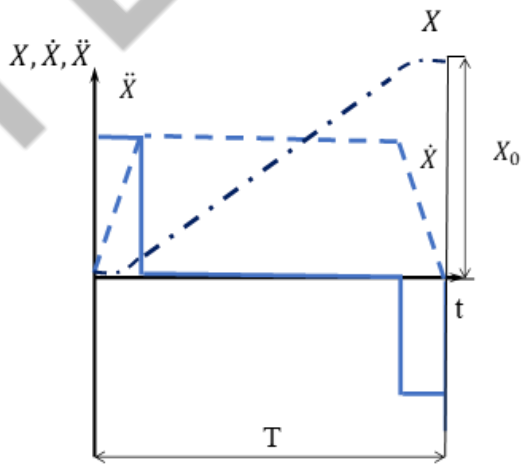
IV. RESULTS

4.1. Experimental stand. The operation of processing artificial products with the help of robot manipulators, in connection with the operation of the gripping elements of the FMM (Fig. 1). The movement of the gripping elements and their control program determine the required performance of the packaging machine or technological equipment. The integrity of the product and the accuracy of positioning of pneumatic grippers depend on the shape, material and law of closing the gripper. Based on the analysis of existing layouts of packaging machines, an electropneumatic positional drive was chosen for the study (Fig. 1a,b). (Fig. 1, c) shows the generalized characteristics of movement, speed and acceleration for the rod connected to the gripping elements using graphs**.**



a)

b)



c)

Fig. 1. The general design of the investigated grippers based on two-way pneumatic cylinders for the robot manipulator: a) a cam gripper system for moving the gripper

elements apart; b) hinged gripper system for opening jaws by 180º; c) general view of soft overlays on gripping elements developed by the authors and printed on a 3D printer (flexible thermoplastic polyurethane thread and PLA with silk thread); d- kinematic characteristics of the output kinematic link (pneumocylinder rod); 1- working piston ring; 2 – sleeve; 3 – body; 4 – guide rod; 5 – damper seal; 6 – piston seal; 7 – rod sealing; 8 – anti-friction plate; 9 – grip finger; 10 – magnet; 11 – piston; 12 – rod; 13 – cover; x,(x,) ẋ ẍ – curves of mixing, speed, acceleration depending on time t; T is the time of the kinematic cycle of the rod; x_0 – movement interval for the full time of movement T;

- The system of the grip shown in the assembly with the pneumatic drive of the robot-manipulator in Fig. 3 works according to the linear - modified [17] law;
- We will limit the overclocking stage to the following conditions: 0<t<0,25T;

$$x = 2x_0\left(\frac{t}{T}\right)^2;\ \dot{x} = 4x_0\frac{t}{T^2};\ \ddot{x} = \frac{4x_0}{T^2}$$

- We will limit the braking stage to the following conditions: 0,75T<t<T;

(1)

$$x = \frac{4x_0 t}{T} - x - 2x_0\left(\frac{t}{T}\right)^2;\ \dot{x} = \frac{4x_0}{T}\left(1 - \frac{t}{T}\right);\ \ddot{x} = -\frac{4x_0}{T^2}.$$

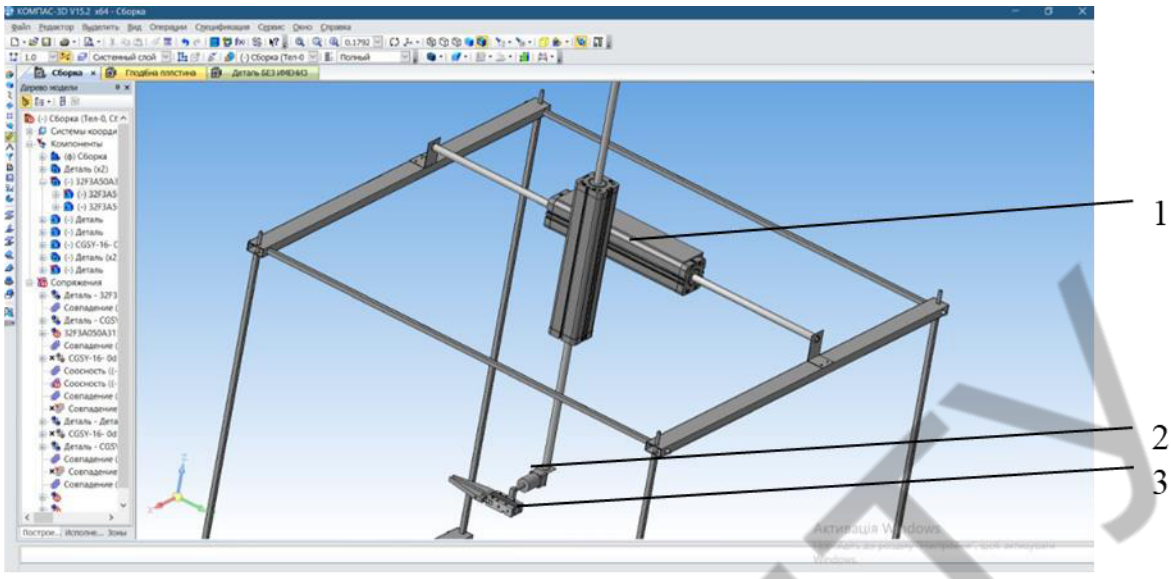
- We will limit the stage of steady motion to the following conditions:0,25T<t<0,75T;

$$x = \dot{x}t;\ \dot{x} = \frac{x_0}{T};\ \ddot{x} = const;$$

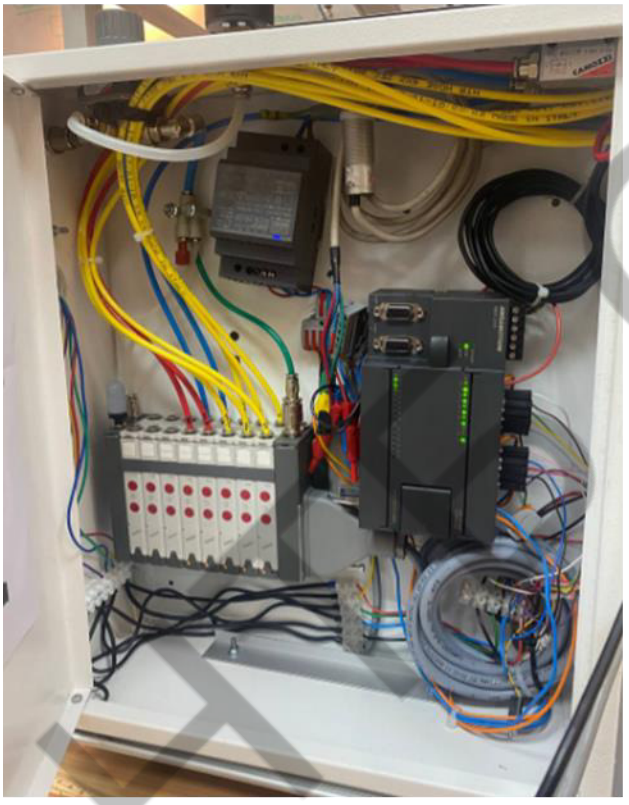
(2)

$$\ddot{x} = \frac{6x_0}{T^2}\left(1 - \frac{2t}{T}\right).$$

The given descriptions of the laws of motion of the working bodies of technological machines [16] do not provide an opportunity to describe in detail the change in the kinematic characteristics of the working bodies in a layout with an electropneumatic drive. Therefore, taking into account (Fig. 1, d) and works [16, 17], we will formulate the research problems with additional parameters. We take the pressure change processes in the power part of the gripper pneumatic drive as such parameters. The research of the manipulator robot, which was designed and assembled by the authors, was carried out taking into account the inertial processes of the power part of the electro-pneumatic drive. Also, there is a need to supplement information on the operation of executive mechanisms of automatic machines [16], in particular, a packaging machine for packing artificial food products based on manipulators. The properly formed structure of the control system, which also needs to be taken into account in research, allows the work of all components of the robot manipulator to be coordinated (Appendix A, the STEP 7-Micro/WIN control program for the position system).



a)



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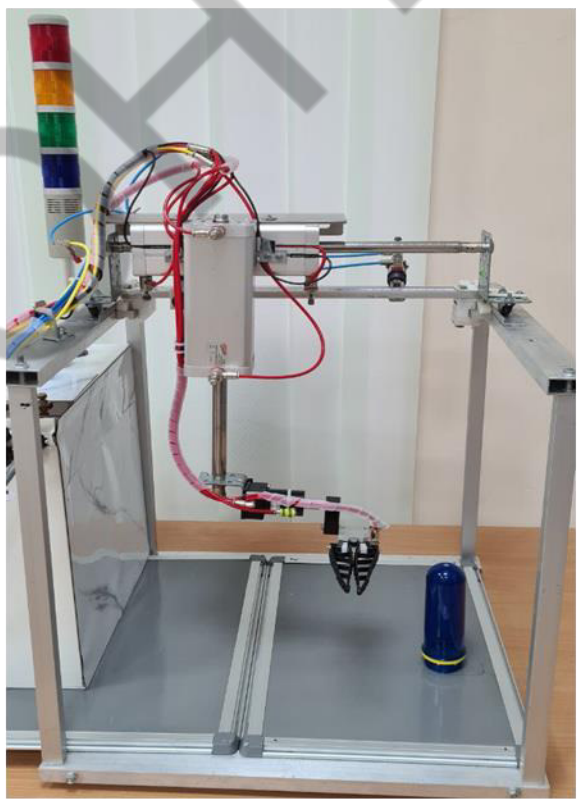

c)

Fig. 2. View of the experimental stand for researching the robot manipulator with a variable pneumatic gripper: a) general view of the 3D experimental stand; b) a general view of the control system of the manipulator module after installation; c) general type of manipulator robot drives: 1 – two-coordinate transport system; 2 – rotary module; 3 – pneumatic gripper with a set of executive elements.

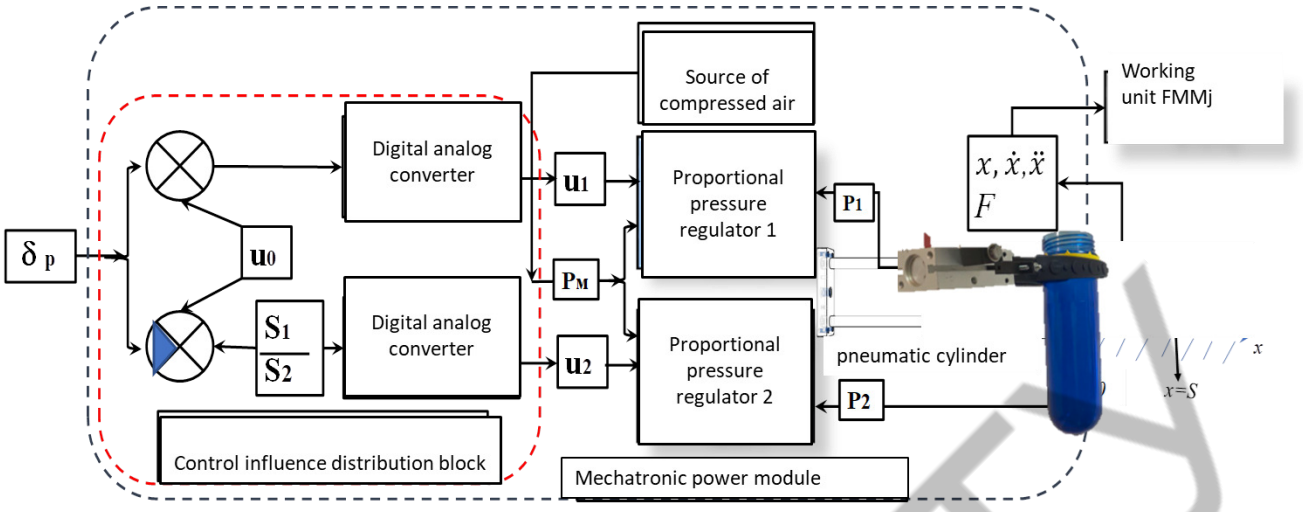

Fig. 3. A generalized diagram of the movement of the cargo during processing with a pneumatic gripper (design in Fig. 1), in a layout with a structural diagram of monitoring the movement of the pneumatic cylinder piston.

4.2. Mathematical model

Thus, the solution of the given problem is reduced to the solution of the optimization problem with initial conditions that are not equal to zero, with subsequent smoothing of the discontinuous function at the moment of turning off the driving force. At the same time, the movement of the piston of the positional pneumatic drive (Fig. 2) consists of four stages:

I stage - initial. The control signal from the electromagnetic relays of the electropneumatic distributor is triggered - and the driving force increases ($Q \le Q(x) \le Q\_max$). The law of motion of the pneumatic cylinder piston takes on a parabolic form. The movement of the working link begins.

II stage - intense acceleration. It ends when the signal of the control electromagnet (first solenoid) disappears. The driving force is constant (Q_max=const). Stage condition: Q_max - the maximum driving force developed by the pusher does not cause deformation of the artificial product.

III stage - transitional. The electromagnetic relay of the electropneumatic distributor (second solenoid) is activated. The driving force decreases ($Q\_max \ge Q(x) \ge Q$) due to the resistance of compressed air in the rod chamber of the pneumatic cylinder.

The IV stage is characterized by the reverse movement of the rod, under the action of intensive braking. The stage ends when the control signal from the second solenoid is turned off. The driving force is zero (Q=0). At the same time, it is necessary to ensure the separation of the product from the pusher. The boundary conditions in this problem are as follows: t=0; $\ddot{x}=0$; $\dot{x}=0$; x=0; $\ddot{x}=\ddot{x}\_IV$; $\dot{x}=0$; x=S.

where S is the amount of movement of the product from the initial position to the final position; $\ddot{x}\_IV$ - the amount of acceleration of the product at the stage of intensive braking.

The variable kinematic characteristics of the pneumocylinder rod are set depending on the x parameter. The equation of motion of the piston of a two-way pneumatic actuator will look like this:

$$m\ddot{x}=p\_1(x)F\_1-p\_2(x)F\_2-P(x) \quad (3)$$

m is the mass of the product; p1, p2 – pressure of piston and rod cavities, F1,2 – piston area of pneumatic cylinder.

We will describe the change in pressure in the form of displacement functions for the piston and rod cavities ofthe pneumocylinder:

$$\frac{dp_1}{dx}=\frac{k}{x_{01}+x}\left[\frac{f_1^э K p_m\sqrt{RT_m}}{F_1}\varphi(\delta_1)\cdot\frac{1}{\dot{x}}-P_1\right] \quad (4)$$

$$\frac{dp_2}{dx}=\frac{k}{S+x_{02}-x}\left[\frac{f_1^э K p_2^{(3k-1)/2k}\sqrt{RT_m}}{F_2 p_m^{(k-1)/2k}}\cdot\frac{1}{\dot{x}}\varphi\left(\frac{\delta_a}{\delta_2}\right)+P_2\right] \quad (5)$$

k – air adiabatic coefficient, x01, x02 – initial and final coordinates of the piston movement, R is the gas constant of air, T_m – air temperature, p_m – pressure of the pneumatic main; φ(δ_1) is the consumption characteristic of the section.

From equation (5), the pressure in the exhaust rod cavity:

$$P_2(x)=\frac{P_1(x)F_1-m\ddot{x}-P(x)}{F_2} \quad (6)$$

After differentiating the function P_2 (x) with respect to the variable x, we have

$$\dot{P}_2(x)=(\dot{P}_1(x)F_1-m\dddot{x}-\dot{m}\ddot{x}-\dot{P}(x))/F_2 \quad (7)$$

From equation (4.4), the effective area of the exhaust hole:

$$f_2^э=\frac{\left[P_2-\frac{dp}{dx}\frac{S+x_{02}-x}{k}\right]\dot{x}F_2 p_m^{(k-1)/2k}}{k p_2^{(3k-1)/2k}\sqrt{RT_m}\varphi\left(\frac{\delta_a}{\delta_2}\right)} \quad (8)$$

Thus, having equations (3-8) that describe the parameters of the movement of the rod taking into account the change in pressure in the pneumatic cylinder, it is possible to proceed to the definition of the equations characterizing the movement of the artificial product on a fixed plane in the complex with the control system (Fig. 3).

Fig. 3 shows a scheme of electropneumatic position drives of a packaging machine. The drives are built by combining into a single module a pneumatic cylinder, reliable and inexpensive serial electro-pneumatic distributors of discrete action, precision sensors of the piston position and a controller that implements a digital relay control algorithm.

To stop the object at various points, feedback from a continuous sensor is used, which measures the current state of the piston relative to the base value. The pneumomechanical subsystem consists of a piston with a rod, a mechanical control object and equivalent pneumatic springs in the cavities of the pneumocylinder. The control

influences u 1 and u 2 on two pressure regulation modules, which are implemented in software using the control influence distribution block. To achieve high speed of the drive and obtain the maximum range of force adjustment, it is advisable to ensure a coordinated change in the effects of u 1 and u 2 according to the equation:

$$\begin{cases} \boldsymbol{u_1 = u_0 + \delta_p}, \\ \boldsymbol{u_2 = (u_0 + \delta_0) \cdot \frac{S_1}{S_2}}. \end{cases} \quad (9)$$

This equation uses the input influence of the mechatronic FP δ p and the reference value u0, which sets the pressure in the cavities of the pneumocylinder at zero input influence, taking into account the difference in the areas of the piston from the side of the rod cavity S1 and the rodless cavity S2. The presence of an FMM with a positional drive is a distinctive feature of the proposed new structure of the mechatronic FP.

Consider the law of motion of the driven link as part of the mechatronic FP. For this you need: to find the Top time of moving the load in the two-stage mode, which is optimal for the speed of action, in order to determine the required value xIk of the moving of the load at the I stage in the four-stage mode (Fig. 2); consider the movement of the load as a three-stage and determine the time of disconnection of the driving force and the total time of movement. At the same time, the final coordinates for the I and III stages of the three-stage movement mode coincide, respectively, with the final coordinates for the I and IV stages of the four-stage movement mode; determine the equations describing the movement of cargo on II and IV, and then on III stage for a four-stage mode of movement.

Such a sequence of the task is related to the determination of the initial and final coordinates of the cargo movement for each stage and the search for integration constants.

The Top time of cargo movement in the two-stage mode, which is optimal for the speed of action, is determined according to the method [9].

$$T_{on} = \sqrt{\frac{2S}{gf(1-m_{\text{rp}}gf/Q)}} \quad (10)$$

where S is the amount of load movement (piston stroke); m_gr – weight of cargo; f - coefficient of sliding friction between the supporting surface of the load and the plane of movement. In table 1, for ease of use, the equations for the kinematic parameters of the moving product and the piston are given in the four-stage motion mode (Fig. 2), when T_оп, T, Qmax, τ and x_τ are known. Changing the parameters of the process of moving the product along a stationary plane and the operating parameters of the positional pneumatic drive at Qmax = 20 H; mass of artificial product m_{gr} =0.5 kg; f = 0.3; S = 0.2 m; F1 =$4.9 \cdot 10^{-4}$ m^2; F2 = $3.77 \cdot 10^{-4}$ m^2; $f1_e$ – variable, depending on the diameter of the main pipeline; Pm=$5 \cdot 10^5$ Pa; m=mgr+mp = 0.5+1.5=2 kg, where mp =1.5 is the mass of the moving parts of the pneumatic cylinder; P(s.tr.) = 20 N – dynamic load of the pneumatic cylinder of the gripper.

4.3. Study of the drive system based on electropneumatic control complexes.

For conducting research, a special stand diagram of connections on (Fig. 4) was designed and manufactured, which makes it possible to simulate different modes of operation of the FMM of supplying consumer packaging to the processing area.

Experimental studies made it possible to check the adequacy of the results of the proposed mathematical models to real processes, as well as to determine important parameters, control systems for which there are no methods of determining them in full.

The stand for experimental research based on the positional drive of the linear movement of the package (Fig. 2, Fig. 4) includes a mechatronic system, a computer with the SIMATIC STEP 7 V5.3 control program, a Siemens S7-300 controller, PtP data exchange (Point to Point) serial interface RS 485. The mechatronic control system is implemented on the basis of a Camozzi 61 series cylinder (stroke 200 mm with a piston diameter of 32 mm), a pneumatic island with connecting holes G3/8, a linear coordinate measuring device of the Balluff company BTL5 series, an analog differentiator for calculation of piston movement speed. The criterion for setting the control circuit is the minimum duration of movement of the output link of the time pneumatic cylinder to the given positioning point and the minimum duration of the drive adjustment when working out the low-speed modes of supplying consumer packaging to the packaging area. During the experimental study, it was found that in the speed control circuit, with the input signal, to ensure a speed of 1 m/s, oscillatory processes are observed (S=f(t)), in particular, the maximum value of the speed varies from 1.5m/s to 2.2m/s, the acceleration increases to 0.25m/s^2. The resulting oscillations in the pneumatic cylinder system indicate that upon reaching the final stop point of the output link (t=0.1c), programmed by the given law of motion of the consumer package, the piston does not reach a steady speed of movement under conditions of weak damping on the speed contour, the presence of frictional forces, as well as interference interference from the location sensor and analog differentiator.

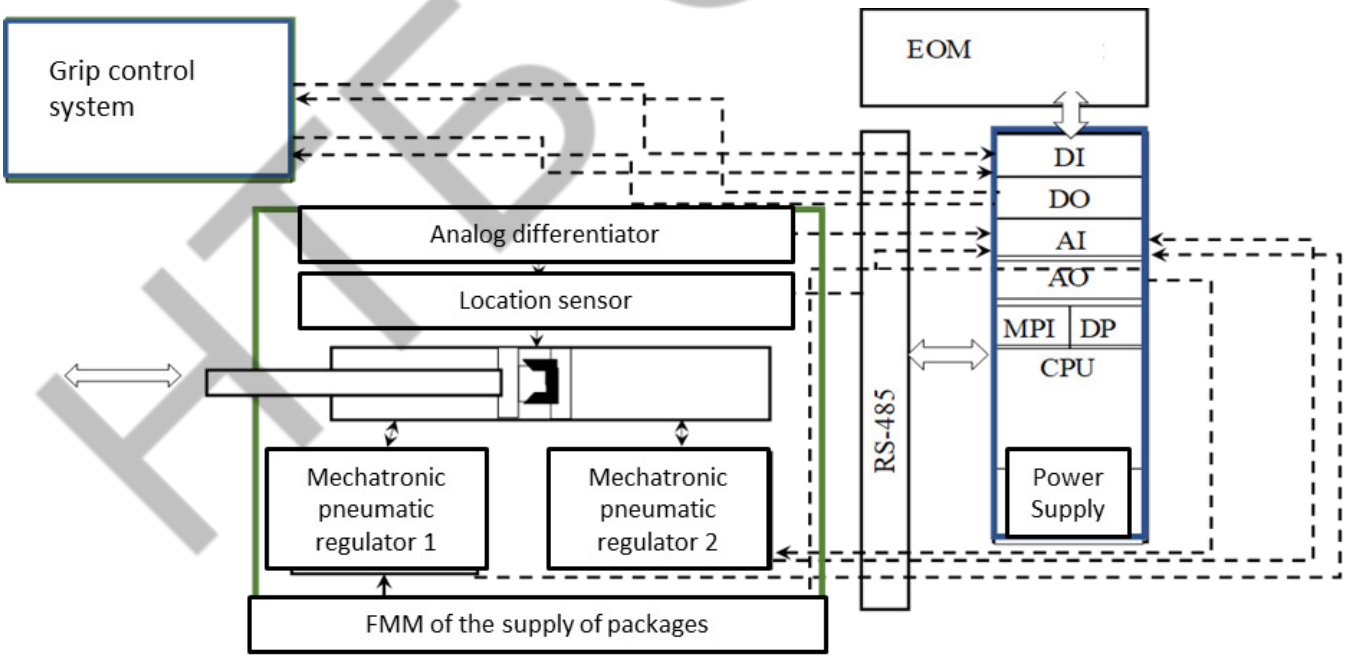

Fig. 4. Structural diagram of the stand for experimental research on the movement and positioning of consumer packaging using a gripper (Addition A,B):

DI – discrete inputs (0-65Hz); DO- discrete outputs; AI - analog inputs (0-10 V, 4-20mA); AO - analog outputs; MPI - information line of data transmission (9.6 Kbt).

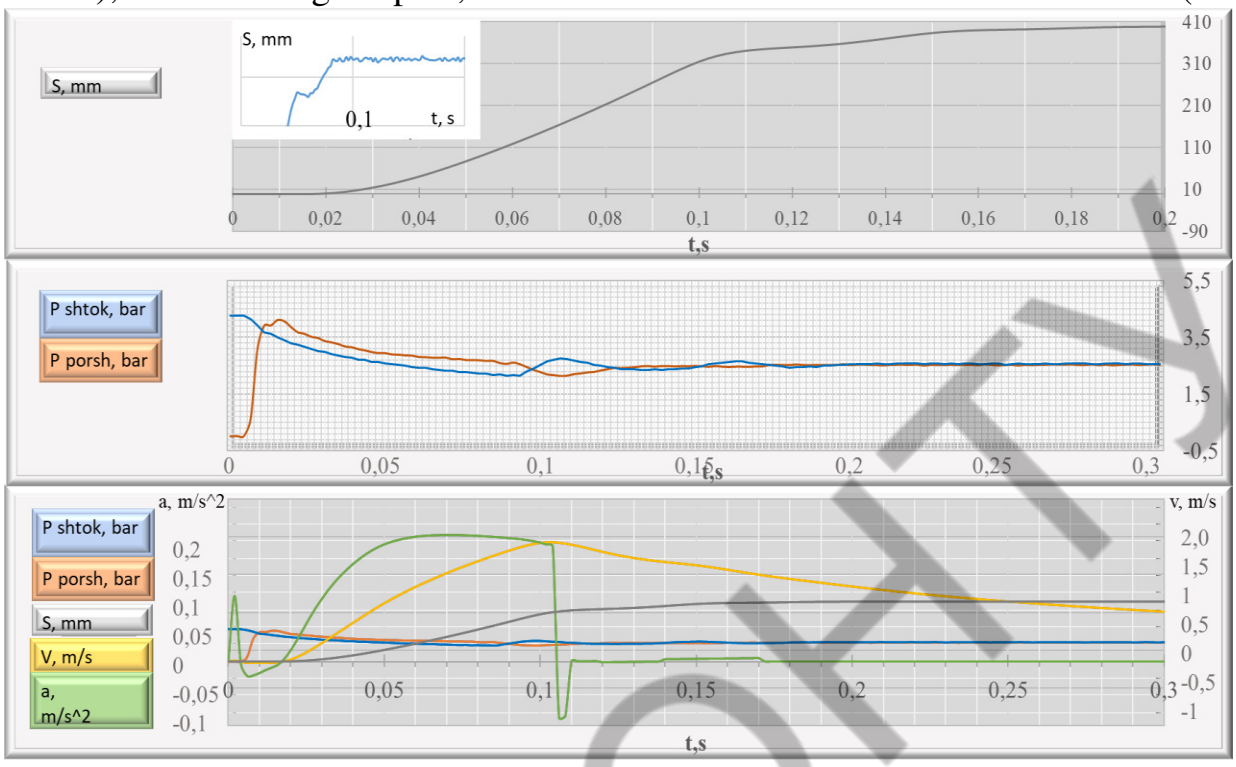

Fig. 5. Generalized kinematic characteristics of the output link of the manipulator during processing of consumer packaging when implementing the law of motion of the piston, which is close to the optimal speed of action: diameter of the pipeline 0.008m, $f_1^e=5.027\cdot10^{-5}м^2$, x is the coordinate of the movement of the piston 0,2m; pneumatic cylinder piston diameter 0.032m; rod 0.016m; working pressure - 0.5 MPa

As a result of mathematical modeling, data were obtained that allow predicting the interaction of the grip of the manipulator robot with objects of various physical and mechanical characteristics and provide kinematic characteristics of the work process.

V. CONCLUSIONS

The motion for the pivoting link of the experimental manipulator robot - pneumatic gripper is implemented and mathematically described. The authors proposed and developed an experimental stand for the study of pneumatic grippers with various forms of contact soft elements. The conditions of the initial air pressure drop in the control drive system of the manipulator robot are taken into account. A mathematical description of the law of motion of the rod optimal in terms of speed of action for the construction of the pneumatic gripper hydraulic drive was obtained. The manipulator robot control program was developed and tested. In the obtained results, it is clearly observed that when the exhaust section of the working cylinder of the positional pneumatic drive is narrowed, the value of the inertial component at the 4th stage (braking) increases. In addition, taking into account the complexity of the working environment - compressed air, it is necessary to enter additional parameters: coefficients of viscous friction of the working kinematic piston-rod pair, resistance coefficients in the exhaust cross-section during the

implementation of the fourth stage of movement. A control system has been developed for an experimental layout with a different set of elements of the output kinematic link. The movement of objects of various geometries by a gripping mechanism with an electro-pneumatic positional pneumatic drive, taking into account the control system, was studied.

The obtained results allow:

- set the working body (pneumatic gripper) to the law of translational motion, close to the optimal speed of action, while not exceeding the maximum allowable dynamic influences for a moving load;
- move the artificial product from the initial position to the final position in the minimum possible time for the pneumatic drive;
- conduct an analysis of the existing designs of executive mechanisms with a pneumatic drive.

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Addition A

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= M0.0
LPP
ALD
O M0.0
= M0.0
Network 2
LDN I0.0
CALL SBR_0
CALL SBR_2
Author: Yemelianov Dmytro, Shevchenko Serhii
COMMENTS
SBR_2 SBR2 SUBROUTINE COMMENTS
Network 3
LD I0.0
CALL SBR_1
Author: Yemelianov Dmytro, Shevchenko Serhii
SBR_1 SBR1 SUBROUTINE COMMENTS
Network 4
LD I0.3
LD Q0.3
CTD C30, +3
Network 5
LD C30
= Q0.3
1 / 5
Author: Yemelianov Dmytro, Shevchenko Serhii / SBR_0
(SBR0)
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Author:
Created: 05/11/2022 10:24:45 am
Last Modified: 01/29/2023 10:42:17 pm
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IN
IN_OUT
OUT
TEMP
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S Q0.0, 1
R Q0.1, 1
Network 2
LDN M0.0
R Q0.0, 1
S Q0.1, 1
2 / 5
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OUT
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Network Comment
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OW>= AIW0, +32000
LD I0.1
EU
OLD
CALL SBR_0
R Q0.2, 1
CALL SBR_1
Symbol Address Comment
SBR_0 SBR0 SUBROUTINE COMMENTS
SBR_1 SBR1 SUBROUTINE COMMENTS
Network 2
LDW>= AIW0, +6000
AW<= AIW0, +6100
LDW>= AIW0, +12000
AW<= AIW0, +12100
OLD
LDW>= AIW0, +18000
AW<= AIW0, +18100
OLD
LDW>= AIW0, +24000
AW<= AIW0, +24100
OLD
EU
R Q0.0, 2
S Q0.2, 1
3 / 5
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(SBR2)
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IN_OUT
OUT
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Network 2 Network Title
Network Comment
4 / 5
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Author:
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Last Modified: 01/29/2023 10:42:17 pm
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TEMP
TEMP
TEMP
INTERRUPT ROUTINE COMMENTS
Network 1 Network Title
Network Comment
5 / 5
```

Addition B

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	TEMP		

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Network 3

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Network 4

```
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Network 5

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Network 6

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TON  T41, 10
```

Network 7

```
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Network 8

```
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Network 9

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Network 10

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TON  T44, 65
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Network 11

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TON  T55, 20
TON  T45, 55
TON  T46, 15
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Network 12

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Network 13

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TON  T47, 15
```

Network 14

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TON  T48, 20
```

Network 15

```
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TON  T49, 15
TON  T51, 25
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Network 16

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S    Q1.0, 1
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Network 17

```
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R    Q1.0, 1
```

Network 18

```
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R    Q1.1, 1
```

Network 21

```
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R    Q0.6, 1
TON  T52, 20
```

Network 22

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TON  T53, 10
```

Network 23

```
LD   T53
S    Q1.1, 1
```

Network 24

```
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```

Network 25

```
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	TEMP		
	TEMP		
	TEMP		

INTERRUPT ROUTINE COMMENTS

Network 1 Network Title

Network Comment

DEVELOPMENT OF A METHOD FOR CALCULATION OF THE ELECTROMAGNETIC COMPATIBILITY REGION OF A RADIO MASKING SOURCE

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Advisor: Olena Novykova
National Academy of National Guard of Ukraine
(Ukraine)

Abstract. *This work is devoted to the problem of determining the electromagnetic compatibility region of a radio transmitter of a radio communication channel in the UHF/VHF range on a terrain map. To solve this problem, mathematical models of radio signal propagation were used, taking into account the characteristics of a particular area. A method is proposed for calculating the boundaries of the electromagnetic compatibility region from a digitized radiation pattern of radio facilities, which is based on the wave algorithm. The results of calculations show that the use of the proposed method is quite effective in solving problems of assessing the performance of a mobile radio communication channel and its security during local combat operations in the conditions of operation of reconnaissance radio receivers or an enemy's intentional radio interference system.*

Keywords: *electromagnetic compatibility region, radio masking source, radio communication system, local combat operations, terrain, mobile radio communication channel, wave algorithm.*

I. INTRODUCTION

When conducting local combat operations by tactical units, taking into account the range of the UHF/VHF radio emission source is an important issue in the tasks of organizing the operation of a mobile radio communication channel. These tasks include [1-4]: analysis of the radio communication channel performance conditions, reducing the effectiveness of enemy radio reconnaissance, protecting the radio channel from the intentional radio interference system. Here, the concept of the electromagnetic compatibility (EMC) region of a radio masking source is used as a set of points in space at which this transmitter provides the minimum required radio signal power at the input of the corresponding receiver, depending on the receiver sensitivity.

II. LITERATURE ANALYSIS

A mathematical model of the EMC of a military radio communication system was proposed in [3-4]. It is based on the representation of the simulated object as a quasi-crystal, based on the provisions of the electromagnetic field theory and the theory of tensor calculus. The authors of [3-4] also give a geometric interpretation of the EMC of a separate military radio station as an indicator of the level of its radio masking. The

presented results do not yet have practical application in solving problems of organizing the operation of mobile radio communication systems.

The paper [5] proposes a method for estimating the EMC region by radio monitoring facilities in the conduct of local combat operations by tactical level subunits in conditions of rugged terrain. This method allows modeling with sufficient accuracy various options for constructing regional radio frequency monitoring subsystems. At the same time, the parameters of the calculated EMC region of radio monitoring facilities depend on the power and radiation pattern of the transmitter antenna, the distance between the receiver and the transmitter, the terrain and the sensitivity of the receiver. The algorithm for calculating the boundaries of the EMC region of radio monitoring facilities in [5] allows to determine the points of intersection of lines of equal heights with the current azimuth on the terrain map and iteratively refines the boundary of the EMC region. Such an algorithm is highly labor-intensive: it takes 15-120 minutes to calculate one EMC region, depending on the terrain, locality buildings and discreteness of readings in azimuth.

As shown in [6], when the subunits of the tactical level conduct combat operations on rough terrain, the mobile radio communication channel is characterized by a short range (up to 5–6 km) due to low transmitter powers (1–5 W). Therefore, to calculate the average value of the attenuation of the radio signal (depending on the characteristics of a particular area), simpler mathematical models of radio signal propagation can be used. This will also speed up the calculation of the boundaries of the EMC region of the radio masking source.

For example, in ideal conditions of free space, the Friis propagation model [7] can be used to estimate the power loss of a radio signal:

$$P_{\mathrm{R}} = P_{\mathrm{T}} G_{\mathrm{T}} G_{\mathrm{R}} \left(\frac{\lambda}{4\pi d} \right)^2 \qquad (1)$$

where P_{R} – the power [W] of the receiving antenna at a distance d [m],

P_{T} – the power of the radio signal transmitter [W],

G_{T} – the antenna gain of the radio signal transmitter in the direction of the receiver,

G_{R} – the gain of the receiving antenna in the direction of the transmitter,

λ – the wave length [m].

For isotropic antennas, when changing to a logarithmic scale, the relation (1) will look like:

$$P_{\mathrm{R}} = P_{\mathrm{T}} - L_{\mathrm{P}}, \text{ [dB]} \qquad (2)$$

where L_{P} – the loss of radio signal power transmission, which in free space [8] is calculated by the formula

$$L_{\mathrm{P}} = 32.44 + 20 \log F_{\mathrm{MHz}} + 20 \log D_{\mathrm{km}}, \text{ [dB]} \qquad (3)$$

where F_{MHz} – the frequency of the radio signal [MHz],

D_{km} – the distance between transmitter and receiver [km].

In the case of combat operations on a flat hilly terrain with an average height of irregularities up to 15 m, it is advisable to use the Egli statistical model [9]. It does not

take into account the diffraction loss that occurs due to the propagation of a radio signal over rough terrain, and also does not take into account the presence of trees and shrubs. In this case, the losses of radio signal power transmission here [10] are calculated by the formula:

$$L_{\text{P}} = 20\log F_{\text{MHz}} + 40\log D_{\text{km}} - 20\log h_{\text{T}} + \begin{cases} 76.3 - 10\log h_{\text{R}}, & h_{\text{R}} \le 10 \\ 85.3 - 20\log h_{\text{R}}, & h_{\text{R}} > 10 \end{cases}, \text{[dB]} \quad (4)$$

where h_{T} – the effective transmitter antenna height [m],

h_{R} – the effective receiver antenna height [m].

When conducting local combat operations in the conditions of urban development and suburbs, it is advisable to use more complex models of Okumura, Hata, and others [10-12].

In this study, to construct a method for calculating the boundaries of the EMC region of a radio masking source as part of a mobile radio communication channel, simpler relations (1), (3), (4) are used to calculate the loss of radio signal power.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The aim of the study is to develop a method for calculating the boundaries of the EMC region of radio masking sources as part of a UHF/VHF mobile radio communication channel with reference to a topographic map of the area with a tactical situation.

To achieve this aim, it is necessary to solve the following tasks:

– to obtain mathematical relationships for determining the EMC regions of radio masking sources, taking into account the losses of the radio signal power;

– to build a fast, simple and reliable algorithm for determining the boundaries of the EMC region of transmitters as part of a mobile radio communication channel;

– to check the feasibility of applying the method for calculating the boundaries of the EMC region of radio masking sources for organizing the operation of a mobile radio communication channel by practical calculations on a topographic terrain map with a tactical situation.

The object of the study is the process of functioning of the radio communication system in the conditions of the use of radio masking facilities.

The subject of the study is the influence of location parameters of active radio masking on the functioning of the radio communication system.

When solving the problems of this study, the following methods were used: the basics of the theory of radio reception – for an analytical description of the interaction of a radio communication system with active radio masking; simulation methods – to analyze the EMC conditions and the effectiveness of the interaction of passive and active radio masking facilities; numerical optimization methods – to optimize the parameters of the system elements by active radio masking facilities; methods for modeling surfaces and solving spatial problems of computational geometry, graph theory – to create algorithms for constructing the boundaries of the EMC region and the zones for the location of active radio masking facilities.

IV. RESULTS

4.1 Determination of the EMC region of radio masking sources in the mobile radio communication channel

Let us consider the interaction of radio facilities of a mobile radio communication channel, taking into account the range of radio masking sources. Let Ω be an area of a topographic terrain map with a tactical situation. Then the proposed model of a mobile radio communication channel in the general case contains the following objects (Fig. 1).

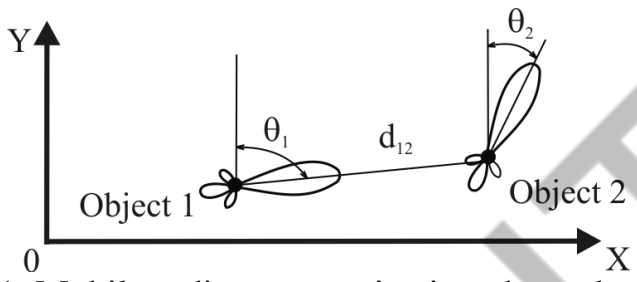


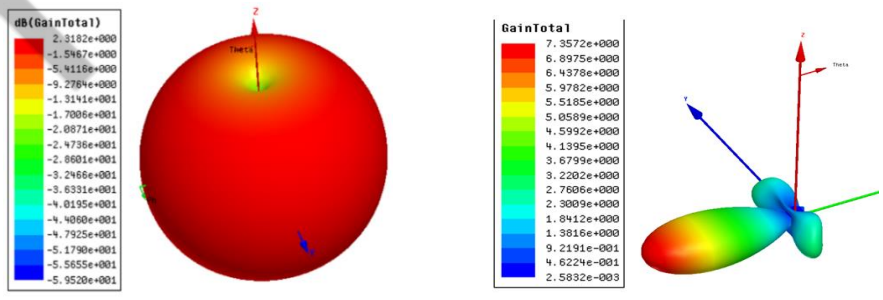
Fig. 1. Mobile radio communication channel model

Object 1 is a ground-based receiver/transmitter of UHF/VHF radio signals with transmitter power P_1 at the point with coordinates $(x_1, y_1) \in \Omega$. The digitized normalized antenna radiation pattern is described by the function $G_1(\theta)$, and the own azimuth of it is the angle θ_1.

Object 2 is a ground-based receiver/transmitter of UHF/VHF radio signals with transmitter power P_2 at the point with coordinates $(x_2, y_2) \in \Omega$. The digitized normalized antenna radiation pattern is described by the function $G_2(\theta)$, the own azimuth of it is the angle θ_2.

Let us assume that the sensitivity of the receivers of both objects is the same and equal to E_s, [μV].

To calculate the digitized antenna radiation pattern of the mobile radio communication facility $G(\theta)$, it is possible to apply the program for modeling three-dimensional electromagnetic fields [13]. Examples of such a calculation of the radiation patterns of omnidirectional and directional antennas of mobile radio communication facilities from [2] are shown in Fig. 2.



a b

Fig. 2. Examples of shapes of digitized antenna radiation patterns in the mobile radio communication channel model [2]:
a – for an omnidirectional antenna, b – for a directional antenna.

Let's move on to solving the first of the study tasks – we will obtain a mathematical relationship to determine the boundaries of the EMC region of the transmitter of object 1, which interacts with the receiver of object 2 when organizing the operation of a mobile radio communication channel. In the case when a matched antenna in mobile radio communication facilities is connected directly to the receiver input with sensitivity E_s and matched active input impedance R_A, the following dependence takes place [13]:

$$P_{\min} = \frac{E_s^2}{4R_A} \qquad (5)$$

The $P_{\min}$ value determines the minimum power of the useful signal that provides high-quality reception at the input of the receiver of object 2. For example, in radio stations Mototrbo™ DP4000 radio stations the receiver sensitivity is 0.25 μV, and for the standard value R_A = 75 Ohm, the minimum value of the radio signal power $P_{\min}$ = – 126.8 dBm [6]. It is logical to assume that at the boundary of the EMC region of the transmitter of object 1, the power of the radio signal at the input of the receiver of object 2 should be at least $P_{\min}$.

According to relation (1), we determine the power of the useful signal of the radio transmitter of object 1 at the location of the radio receiver of object 2, taking into account the functions of the digitized antenna radiation patterns:

$$P_{12}(x_2, y_2) = P_1 G_1(\theta_{12} - \theta_1) G_2(\theta_{21} - \theta_2) \left(\frac{\lambda}{4\pi d_{12}} \right)^2 \qquad (6)$$

where P_{12} – the signal power of the receiving antenna of the radio receiver of object 2 [W],

P_1 – the signal power from the transmitter of object 1 [W].

According to relation (3), on a logarithmic scale, we calculate the signal powers P_{12} and P_1 as:

$$P_{12}(x_2, y_2) = P_1 + 10\log\left[G_1(\theta_{12} - \theta_1)\right] - L_P \text{ , [dBm].} \qquad (7)$$

Thus, with the minimum required power of the useful signal $P_{\min}$, it is possible to determine the EMC region of the transmitter of object 1 for the receiver of object 2 as

$$\Omega_{E_1} = \left\{ \forall (x_2, y_2) \in \Omega \mid P_{12}(x_2, y_2) \geq P_{\min} \right\} \qquad (8)$$

and the EMC region of the transmitter of object 2 for the receiver of object 1 as:

$$\Omega_{E_2} = \left\{ \forall (x_1, y_1) \in \Omega \mid P_{21}(x_1, y_1) \geq P_{\min} \right\} \qquad (9)$$

where

$$P_{21}(x_1, y_1) = P_2 + 10\log\left[G_2(\theta_{21} - \theta_2)\right] - L_P \text{ , [dBm]} \qquad (10)$$

To ensure the operability of the mobile radio communication channel, a necessary condition is the simultaneous placement of the receivers of objects 1 and 2 in the adjacent EMC regions of the radio channel transmitters:

$$\begin{cases} (x_1, y_1) \in \Omega_{E_2} \\ (x_2, y_2) \in \Omega_{E_1} \end{cases} \quad (11)$$

Thus, from the relations (7)-(11) obtained, it follows that the size of the EMC region and the fulfillment of the conditions for the operability of a mobile radio communication channel depend on their power, the orientation of the antenna radiation pattern, power losses in the signal propagation path and the sensitivity of the radio signal receiver.

4.2 Algorithm for determining the boundaries of the EMC region of the source of radio masking as part of a mobile radio communication channel

Let us take as a basis the modification of the wave algorithm from [2].

A topographic terrain map with a tactical situation in the form of a pixel matrix can be represented as a discrete workspace, which is limited by the coordinates x_{min}, x_{max}, y_{min}, y_{max}. The Mask array is used to describe the state of the cells of this workspace (as Mask array is array [x_{min} .. x_{max}, y_{min} .. y_{max}] of boolean). In it, a free workspace cell with coordinates (x, y) corresponds to the Mask[x, y] = False state, and a non-free workspace cell with coordinates (x, y) corresponds to the Mask[x, y] = True state. The coordinates of the points of the old and new wave fronts are accumulated respectively in the Front array (as array[1…L_f] of record x, y: integer end) and Fnew array (as array[1…Lfnew] of record x, y: integer end).

The algorithm for calculating the boundaries of the EMC region of the radio masking source is shown in Fig. 3 and consists of three stages: initialization (block 1), wave propagation (blocks 2-14) and formation of an array of coordinates of the region boundary (8) (blocks 15-30).

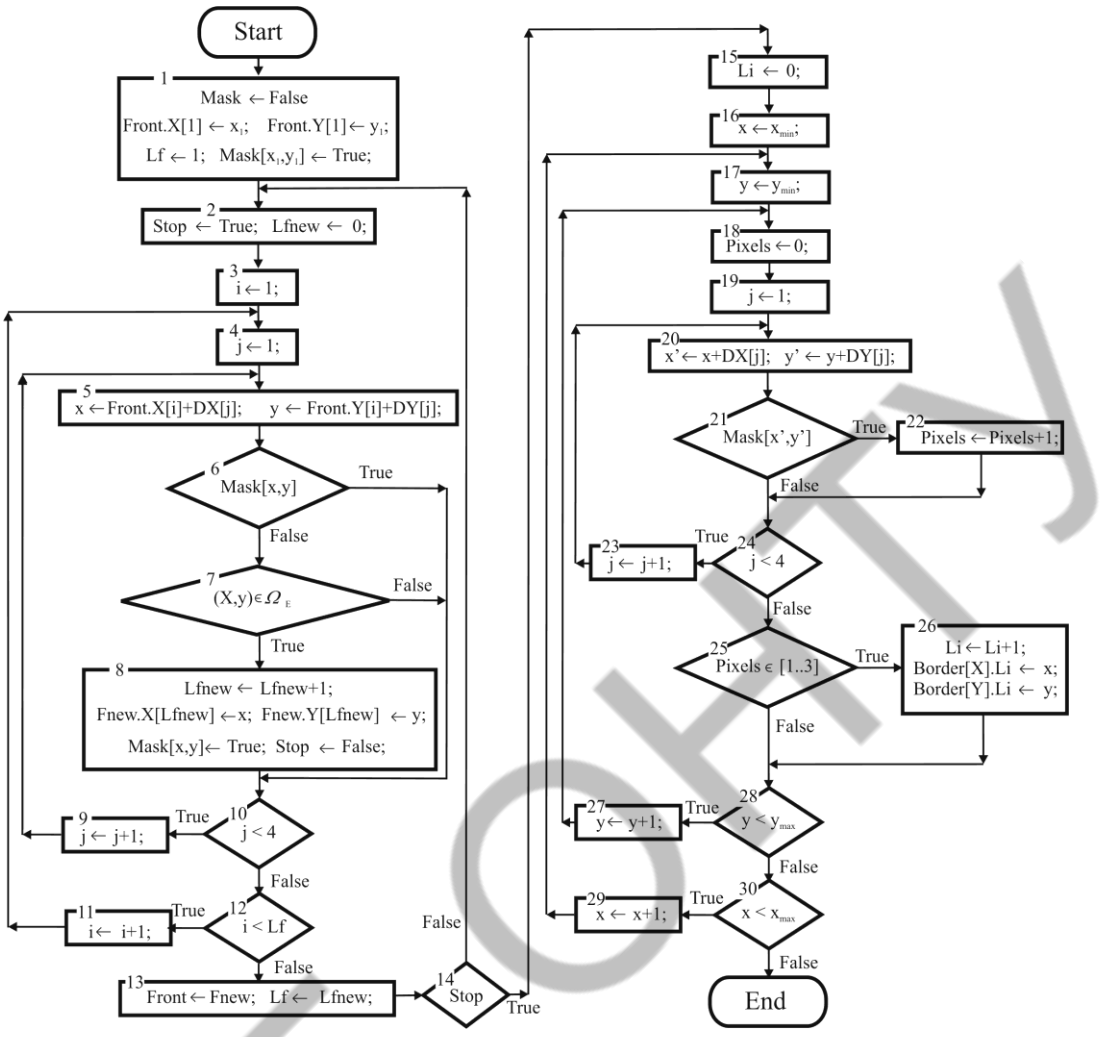


Fig. 3. Algorithm for calculating the boundaries of the EMC region of a radio masking source

At the initialization stage, it is assumed that all cells of the discrete workspace are free, therefore, all elements of the Mask array are set to False. The transmitter location point (x_1, y_1) is chosen as the starting cell, so the corresponding element of the mask array changes its value to Mask[x_1, y_1] = True. The coordinates of the starting cell are also written to the Front array. Wave front length Lf = 1.

At the stage of wave propagation, the arrays Fnew, Front, and Mask are updated cyclically. For each point of the old wave front, using the working arrays DX (0,1,0,-1) and DY (-1,0,1,0), the coordinates of adjacent points are calculated (block 5). If the candidate point with coordinates (x, y) is free (block 6) and the condition (8) is satisfied (block 7), then the candidate point with coordinates (x, y) is included in the new front (block 8). The corresponding element of the Mask[x, y] array is set to True.

At the end of the cycle of polling adjacent points and the cycle of scanning the points of the current wave front (blocks 11, 12), the Fnew array is rewritten to the Front array (block 13). The process of wave propagation ends at the boundary of the region,

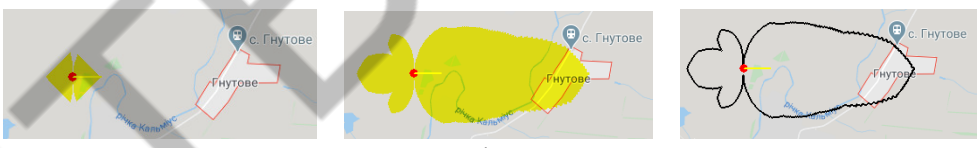
when the condition (8) ceases to be satisfied for any candidate points. In this case, the Stop flag switches to the next stage of the algorithm.

Attention should be paid to the rule for determining whether the current point of the discrete working field belongs to the EMC region of the radio masking source in block 7. The transition from the Friis radio signal propagation model to the Egli model in this block is easy to do, taking into account relations (3) or (4), respectively, in equations (7) and (8).

Next comes the stage of laying the boundaries of the region. After resetting the counter of boundary points of the region L_i (block 15), the points of the working area of the map x_{min}, x_{max}, y_{min}, y_{max} are scanned using the Mask array (blocks 16...30). For each point with coordinates (x, y), the Pixels parameter is calculated – the number of adjacent points whose bit mask is set to True (blocks 21 and 22). If for the current point (x, y) the Pixels parameter lies in the range of values from 1 to 3, then this point is included in the region boundary (8) and stored in the array of coordinates of the region boundary points – Border (blocks 25 and 26).

On Fig.4 shows the visualization of the results of the phased operation of the algorithm when calculating the boundaries of the transmitter EMC region with reference to the terrain map; the map was taken from Google Maps at a scale of 19 m/pixel.

Wave propagation starts from the transmitter location point ($x1$, $y1$); map points (x, y) for which Mask[x, y] is set to True are shown in yellow (see Fig. 4a). The wave stops propagating when the Stop flag is set to True (see Fig. 4b). Next, the region boundaries Ω_E are drawn (see Fig. 4c). These results of the phased operation of the algorithm for calculating the boundaries of the EMC region of the radio masking source were obtained for a transmitter with a power of 1 W (when operating at a frequency of 446 MHz) and for a receiver sensitivity of 0.25 μV.



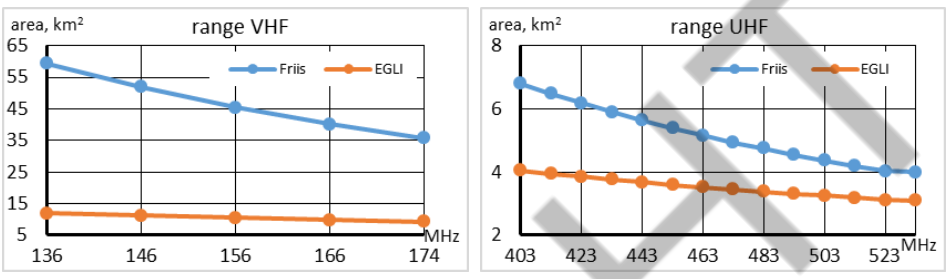
a b c

Fig. 4. The results of the phased work of the algorithm for calculating the boundaries of the EMC region of the radio masking source:
a – the beginning of wave propagation, b – the ending of wave propagation, c – laying the region boundaries

The maximum distance from the transmitter location to the EMC boundary points is 3.629 km, which corresponds to the main lobe of the antenna radiation pattern. It is also possible to estimate the area of the received region Ω_E of the transmitter by calculating the number of cells in the Mask array with the True state (with reference to the map scale). So, for example, in the given example (Fig. 4), the area of the region Ω_E turned out to be 5.56 km2, which is 3% of the total area of the topographic terrain map with the tactical situation Ω. An analysis of the results of the calculations allows us to

state that the area of the EMC region increases by a factor of 1.56 with an increase in the sensitivity of the radio receiver by 0.05 μV.

During the study, the dependences of the area of the EMC region of the Mototrbo™ DP4000 radio station [6] on the signal frequency in the VHF (136–174 MHz) and UHF (403–527 MHz) bands were obtained, which are shown in Fig. 5. Analysis of the calculation results allows us to conclude that with a decrease in the frequency of the radio signal, the size of the EMC region increases: for the Friis signal propagation model – by 1.7 times, and for the Egli signal propagation model – by 1.3 times. There is also a tendency for the sizes of the EMC region to converge for different models with increasing frequency in the UHF range



a b

Fig. 5. Dependence of the size of the EMC region of the radio masking source on the signal frequency:
a – VHF band, b – UHF band

By calculating the EMC regions, it is also possible to assess the fulfillment of the conditions for the operability of a mobile radio communication channel (11). On Fig. 6 shows two options for calculating adjacent EMC regions of an operable radio channel for omnidirectional and directional antennas, which were carried out for a radio transmitters power of 1 W and a radio receivers sensitivity of $E_{s1} = E_{s2} = 0.25$ μV. For both options, the conditions for the operability of the mobile radio communication channel (11) are satisfied.

a b

Fig. 6. Examples of calculation of EMC regions of radio facilities of a mobile radio communication channel:
a – for omnidirectional antennas, b – for directional antennas

The presence of EMC regions of radio facilities of a mobile radio communication channel should also be taken into account when they operate in the presence of reconnaissance radio receivers or a enemy's intentional radio interference system.

V. CONCLUSIONS

As a result of the study, mathematical relationships were obtained to determine on the terrain map with the tactical situation of EMC regions of radio masking sources as part of a mobile radio communication channel, taking into account the loss of radio signal power. For this, Friis and Egli's mathematical models of radio signal propagation were used, taking into account the characteristics of a particular area.

The proposed method for determining the boundaries of the EMC region of transmitters of a mobile radio communication channel is characterized by simplicity, high speed and reliability of calculations. According to the research results, the duration of calculating the EMC region of radio masking sources on a topographic terrain map, taking into account the tactical situation, is on average 0.8..1.5 seconds.

The shape of the EMC region is determined by the digitized radiation pattern of the transmitter antenna obtained using special software.

The size of the EMC region depends on the power and frequency of the radio transmitter, the power loss along the signal path, and the sensitivity of the radio signal receiver. An analysis of the results of the calculations shows that the area of the EMC region increases by a factor of 1.56 with an increase in the sensitivity of the radio receiver by 0.05 μV. With a decrease in the frequency of the radio signal, the size of the EMC region increases: for the Friis signal propagation model – by 1.7 times, and for the Egli signal propagation model – by 1.3 times. There is also a tendency for the sizes of the EMC region to converge for different models with increasing frequency in the UHF range.

Practical calculations on a topographic terrain map with a tactical situation have shown the feasibility of using the method of calculating the boundaries of the EMC region of radio masking sources in the tasks of organizing the operation of a mobile radio communication channel.

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AUTOMATIC WAGON LOADING CONTROL SYSTEM USING INDUSTRY 4.0 TECHNOLOGIES

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Purpose: *the development of a system for automatic control of car loading, which will be able to combine separate nodes into one common system to ensure greater control and reliability of the process. Research methods are grapho-combinatorial.*

Methodology: *the research is justified by a logical synthesis based on the hardware of embedded control systems, programming in the language of functional blocks of the MEK61131-3 standard.*

Results: *the requirements for the structure of the automation system of coal loading complexes were formulated, the basic automation equipment was selected, and the control algorithms were determined. Based on the requirements for the automation system, a functional scheme and its technical implementation of the automation of coal loading complexes as a single control system were developed. The algorithm was developed and subsequently the SAC program of the local system was developed, which was able to show its performance in the "Owen Logic" environment. This made it possible to adjust and select the correct coefficients and possible calculated data.*

Scientific novelty: *the development of a functional model of the coal loading complex and the use of wireless communications, aimed at combining fragmented local systems into one common one to ensure greater control and reliability of the process.*

Practical significance: *the functional and structural model of the coal loading complex will allow to increase its level of automation, reliability and efficiency of operation, to eliminate the shortcomings of the technical fragmentation of the system and to prevent significant material, time and economic costs for setting up the system.*

Keywords: *automatic control system, algorithm, programming, wireless communication, controller.*

I. INTRODUCTION

In the modern world, much attention is paid to the development of the coal mining industry, but it faces the problems of improving the quality of automated processes and reducing the human presence in the technological process, the efficiency of the use of transport and technological equipment.

Shipment of coal to consumers is the final stage of mine operation. Coal loading is carried out through a coal loading point where coal is supplied from storage bunkers or

from coal warehouses on the surface of the mine.

In addition to quality control, shipped coal is subject to quantitative control, which is of a commercial nature when calculating consumers with a mining enterprise.

The main type of external transport of coal from mines is railway transport.

In order to achieve an increase in the efficiency of coal loading complexes, a number of measures have been created to improve the process of loading coal into railway cars. From the obtained results, automated coal loading complexes appeared.

The mandatory presence of such installations is due to the growth of coal consumption, and therefore of coal mining sites, due to which it is necessary to increase the quality level of coal loading by fully automating the loading process.

II. LITERATURE ANALYSIS

An analysis of modern models of coal loading complexes [1-2] was performed, an analysis of automation in metallurgy was performed [3-4], an analysis of data transfer in automation systems was performed [5-6].

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The facility is a coal-loading complex that can combine individual units into one common system to provide greater process control and reliability. The subject of research is an automatic control system. The conducted research was based on the general provisions of the theory of automatic control and the theory of designing computerized systems using Industry 4.0 technologies.

IV. RESULTS

Existing systems of automated control of coal loading of wagons have certain shortcomings that complicate the process of maintenance and analysis of the system. The system is divided into separate nodes that work separately and do not communicate with each other. This shortcoming does not allow full control of the loading process, which in turn leads to a decrease in productivity and an increase in crashes.

Based on a detailed analysis of the coal loading system and the conclusions drawn in the previous section, I propose to develop a SAC that can combine individual nodes into one common system to ensure greater control and reliability of the process.

The basis of the designed system is the principle of control and transmission of information of individual nodes using a cloud service with subsequent transmission of information to the dispatcher's console and control of these nodes using a programmable logic controller. Using a cloud service will allow us to transmit information wirelessly, so we can reduce the cost of resources for a wired connection. And the controller will make it possible to build a distributed control and dispatching system that can be used within the framework of one device.

Functional diagram of SAC. For the design of the modernized SAC of the coal loading complex, a functional scheme was developed, which is shown in figure 1.

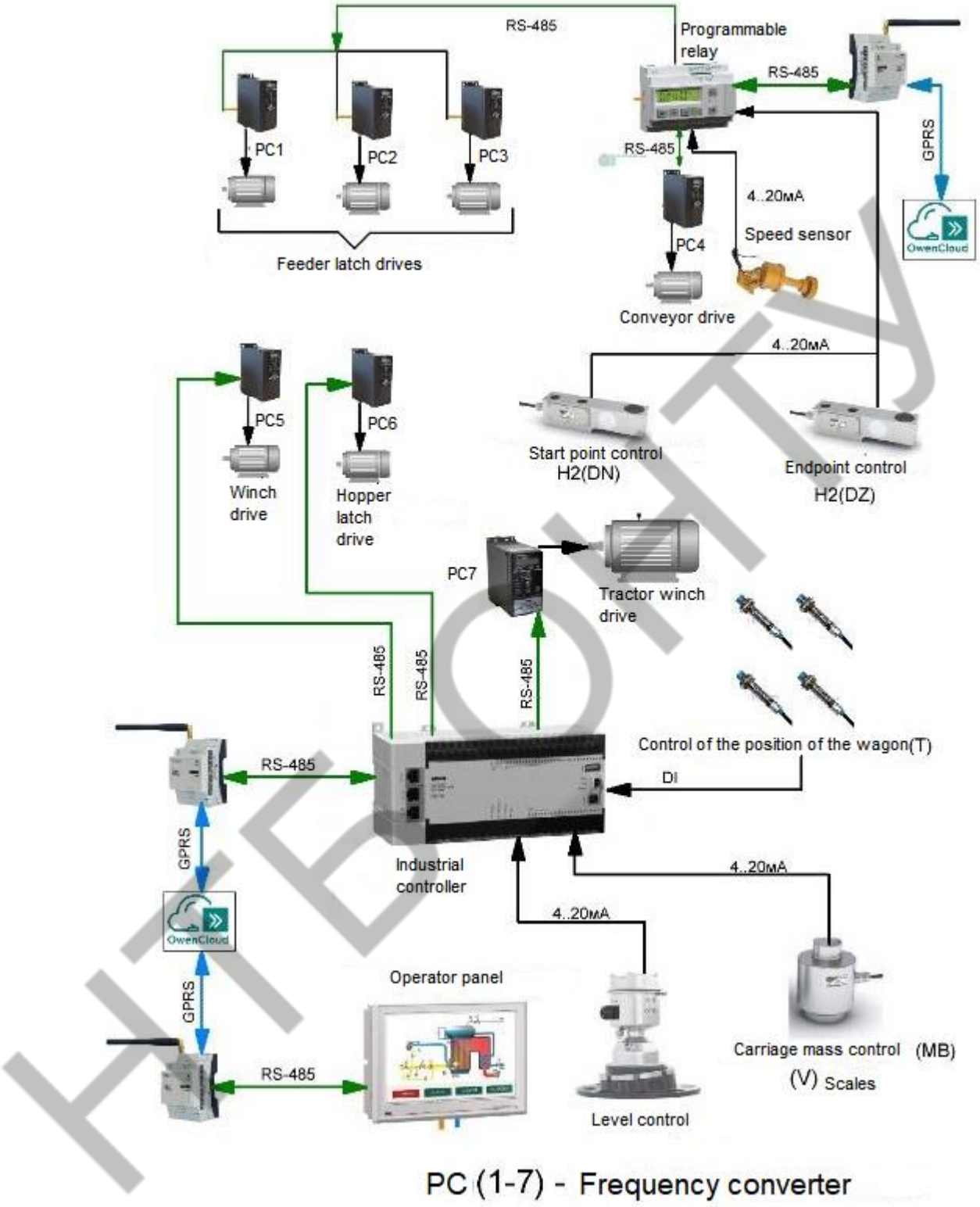


Fig. 1. Functional diagram of the modernized automatic control system

The developed SAC should ensure automatic loading of the wagon by volume and weight, uniform distribution of the coal "cap" in the wagon, reading of data from all sensors, unification of nodes of the coal loading complex into a single automated system

in order to have the possibility of automatic adjustment of the loading process during the loading process.

In order to find the optimal parameters, such as the speed of the conveyor belt, the opening angle of the feeder valve and the drive speed of the tractor winch, it is necessary to know the actual values of the weight of the car and take into account the level of occupancy of the car. We measure the mass of the wagon with the help of a strain gauge built into the track scale to calculate the mass of the wagon by software. This is necessary for reporting on the weight of the cargo. A conveyor speed sensor is required to control belt slippage. The initial (DN) and final (DZ) position of the conveyor is determined by strain gauges installed on the conveyor belt. We use a level sensor to measure the level of occupancy of the car. Inductive sensors are necessary to record data about the position of the car. In this way, the data from the strain gauge in a pair with the inductive ones make it possible to adjust the speed of the winch drive. The data from the strain gauges (DN) and (DZ) together with the data on the mass and occupancy level of the car adjust the speed of the conveyor belt. The opening angle of the feeder shutter is adjusted based on the output data from the tape speed sensor, i.e. the higher the speed, the more the feeder shutter opens.

The basis of the system is a programmable logic controller. It takes over all the calculations of the data it receives from the sensors, i.e. it calculates the mass, loading level and speed. Based on the received calculations, the PLC issues tasks for all control mechanisms. The controller has frequency converters, a programmable relay and an operator panel for outputting information. For frequency converters, the frequency calculated by the controller is set. The programmable relay is a separate subsystem that also communicates with the frequency converter and receives and processes information from the sensors.

Development of SAC algorithms. The development of algorithms for the automatic control system of the coal loading complex is necessary for writing software and creating a single system based on an industrial controller. Algorithms are developed on the basis of the requirements for the automatic control system described above in the work and the created and described modernized functional scheme with all selected equipment.

The development of algorithms of the main system and the local system is expected. The main system is controlled by PLC160 controller. The local system is based on a programmable relay and controls the feeder valves and the conveyor drive. An application will be created in the OwenLogic environment for the local system.

To begin with, it is necessary to describe how the system works as a whole in order to create block diagrams of algorithms for further development of the control system. In the functional diagram, which is presented in the previous section in Figure 1, the process begins with the operator's panel, where it is necessary to choose the control mode, manual (manual is necessary for rolling back the system) or automatic. In automatic mode, the start signal from the operator panel is output via RS485, then the signal is converted using the PM210 network gateway and then transmitted to the PLC160 industrial controller. In the next step, the PLC160 processes the signal and issues the corresponding command to

the frequency converter (IF7), which controls the winch drive to start the movement of the railway stock. After the operation of the first pair of inductive terminals, which are installed behind the fixing supports, the signal is transmitted to the controller and the input to the frequency converter (IF7). The frequency converter (IF7) reduces the speed of the drive by reducing the frequency by software with the command word received from the PLC160. When the second pair of inductive sensors are activated, the signal from them and the strain gauge (MV) will be processed by the PLC and provide information to the operator's panel regarding the weight of the car and readiness for loading.

The signal from the PLC is fed to the programmable relay through the network gateway, the relay receives and processes the signal and outputs it to the frequency converter (IF4), which starts the conveyor, and later sends signals (IF1), (IF2), (IF3) that control the actuators of the feeder valves. At the same time, the programmable relay receives signals from the speed sensor of the conveyor belt and strain gauges (DN), (DZ) and, based on these data, regulates the speed of the conveyor belt and the opening of the feeder valves. As soon as the signal from the strain gauge (DN) becomes zero, the PR200 will send a signal to the PLC160, which will start the drive of the roller winch (PC5) to form the wagon cap.

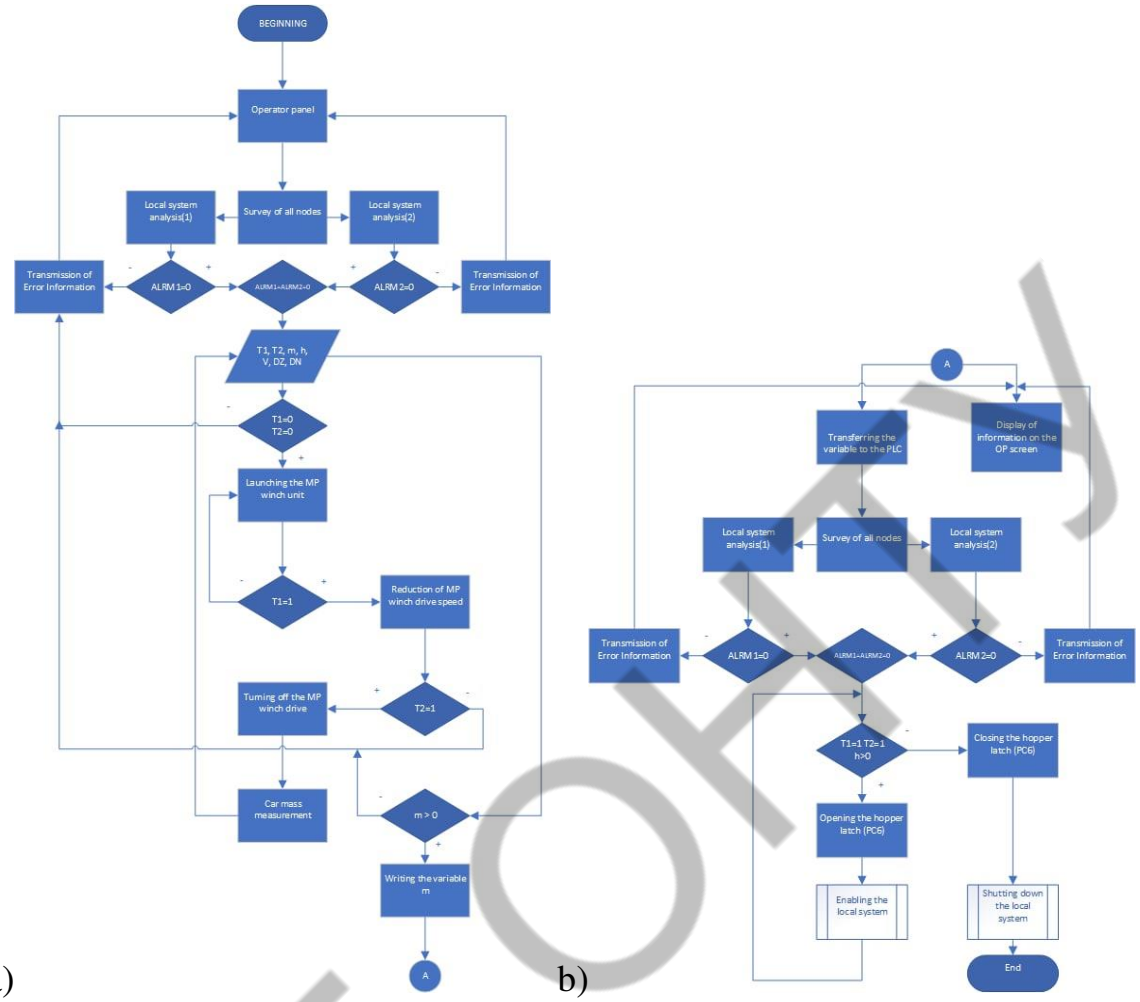
After the activation of the level sensor and the strain gauge (MV), the PLC transmits a signal to (IF6) to close the hopper valve, and to stop the supply of coal to the hopper to the programmable relay, which in turn first closes the feeder valves, and then stops the conveyor.

The signal to stop the conveyor and close the shutters is sent to the PLC, which in turn starts (PC7) the drive of the winch, which pulls up the next wagons for loading.

The block diagram shown in Figure 2 (a) describes the algorithm by which loading into railway cars is performed. The beginning of the program begins with a survey of all control nodes and analysis of local systems, which include systems controlled by PLC160 and PR200. If an error was detected, the system transmits the error code to the operator panel, where the operator then makes a decision to eliminate the error. If no errors are detected and the output signal ALM1 and ALM2 are equal to zero, the system proceeds to the next step. Next, the system records initial data from all sensors connected to the system. These are data from inductive sensors, weight data, data from a level gauge and strain gauges. Then there is a check for the absence of a car on the filling platform, this is necessary in order to avoid a collision. After the inspection, the process of adjusting the wagon under the filling hopper with the help of a maneuvering device begins. After turning off the shunting device, the weight of the wagon is measured and the next step of filling the wagon is carried out.

The next step of the algorithm is the transfer of the already defined variables to the PLC and the output of the corresponding information on the readiness of filling the railway stock on the operator panel.

Similarly to the previous step, all nodes are polled and local system data is compared. In the event that no errors are detected, the transition to the step where the received signals are compared and the hopper valve control unit is started, after which the transition to the local system follows.



a) b)

Fig. 2. Block diagram of the main program:
a – the algorithm of loading into railway cars, b – the algorithm of loading into railway cars (continued)

The development of the program for the local system of the coal loading complex will take place in the OwenLogic environment. First of all, this is due to the fact that almost the entire automatic control system is built on the basis of devices from the "ARIES" company, it is also a fairly convenient tool for building a SAC. The programming language that will be used in the environment is the language of functional blocks that meets the MEK61131-3 standard.

The system of automatic control of wagon loading uses a number of drives, namely electric motors under the control of frequency-vector converters (FVC).

To set the engine speed, the control unit calculates based on engine data and input signals.

The formula for calculating the output frequency for frequency converters that control feeder gate drives. The frequency for FVC 1 is calculated by the formula:

$$\omega_1 = ((2 \cdot \vartheta_1) \cdot P_n) \div 100, \quad (1)$$

where, ϑ_1 – speed from the first sensor; P_n – the starting case of the task; ω_1 – output frequency for FVC 1.

The frequency for FVC 2 is calculated by the formula:

$$\omega_2 = ((3 \cdot \vartheta_2) \cdot P_n) \div 100, \quad (2)$$

where, ϑ_2 – speed from the first sensor; P_n – the starting case of the task; ω_2 – output frequency for FVC 2.

The frequency for FVC 3 is calculated by the formula:

$$\omega_3 = ((4 \cdot \vartheta_3) \cdot P_n) \div 100, \quad (3)$$

where, ϑ_3 – speed from the first sensor; P_n – the starting case of the task; ω_3 – output frequency for FVC 3.

Given the output frequency and a properly configured frequency converter, we can obtain the rotational speed as a function of frequency. The rotation speed is calculated by the formula:

$$\vartheta_i = (N_m \div 100) \cdot \omega_i, \quad (4)$$

where, ϑ_i – the rotation speed of the motor in rpm of the i-th converter, where "i" is from 1 to 3; N_m – nominal engine revolutions per minute; ω_i – the output frequency of the i-th converter, where "i" is from 1 to 3.

To start working in the environment, it is necessary to create a new project and select a model range of the device.

After creating a new project, you need to create variables that will be used when writing the program.

Among the input variables that come to the programmable relay from the sensors, we record the speed with the integral variable type, final (DN) and (DZ) with the Boolean variable type.

It is also necessary to add variables that will be used by the network gateway, frequency converters.

The next step is to create a frequency converter control unit. Since the program does not provide for such a functional block, we will create it ourselves.

The program turns out to be very cumbersome, so the FVC control unit (PCV) was compiled into a macro.

It is necessary to add four more FVC control blocks (PCV1-4) to the program, and create one for each task.

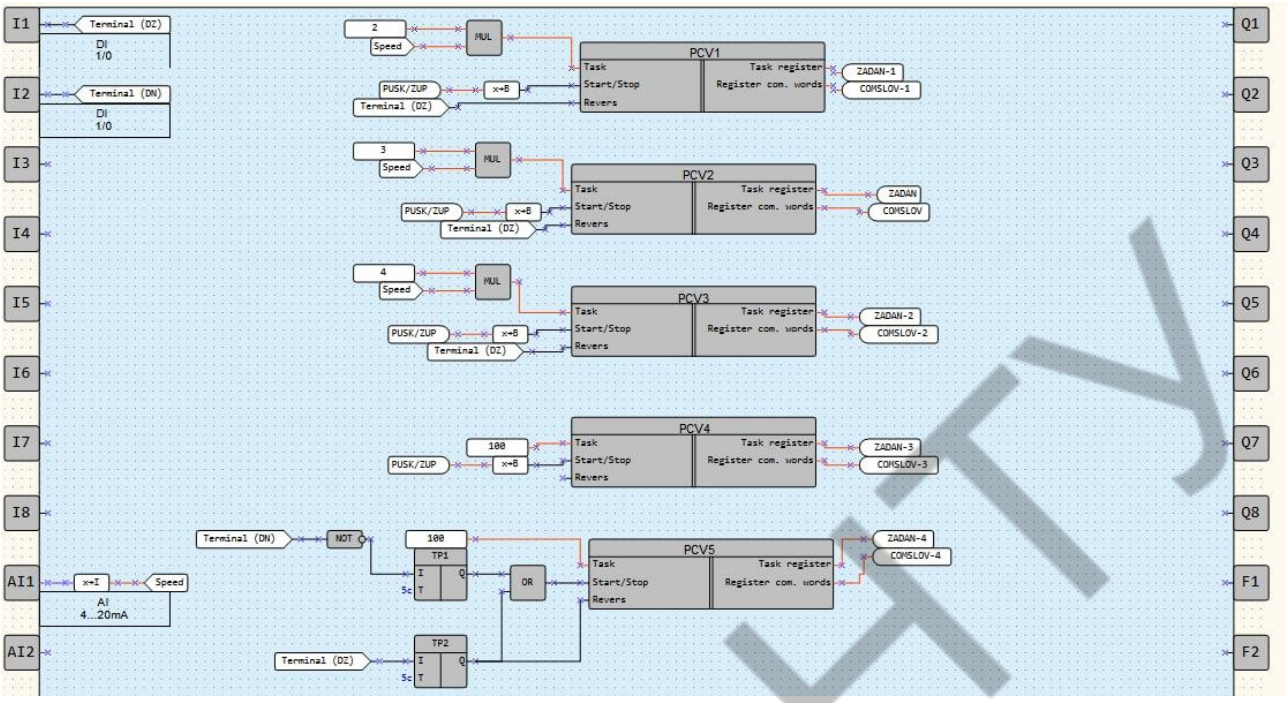


Fig. 3. Program for local system

Figure 3 shows the control program for the local system. On it, we can see the tasks for each PCV macro. For PCV(1-3) we use the following principle, when the signal from the speed sensor (AI1) arrives, we convert it into an integer and feed it to the MUL multiplication block, here we feed the multiplication factor, which depends on the angle at which the valves will open. The shutter is closed after the end (DZ) is triggered.

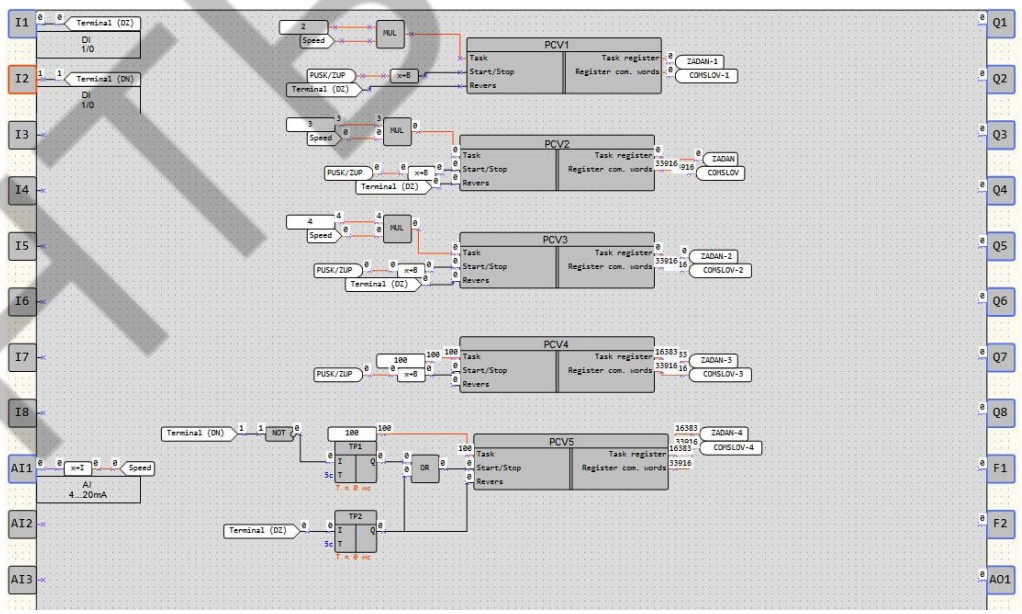


Fig. 4. Start of the program

Frequency converter number four has a constant frequency of operation and is controlled by the network variable PUSK/ZUP, PCV5 is responsible for the roller winch, which is started after disconnection of the end (DN) with a signal delay of 5 seconds. This is necessary so that the winch has time to move to the required distance.

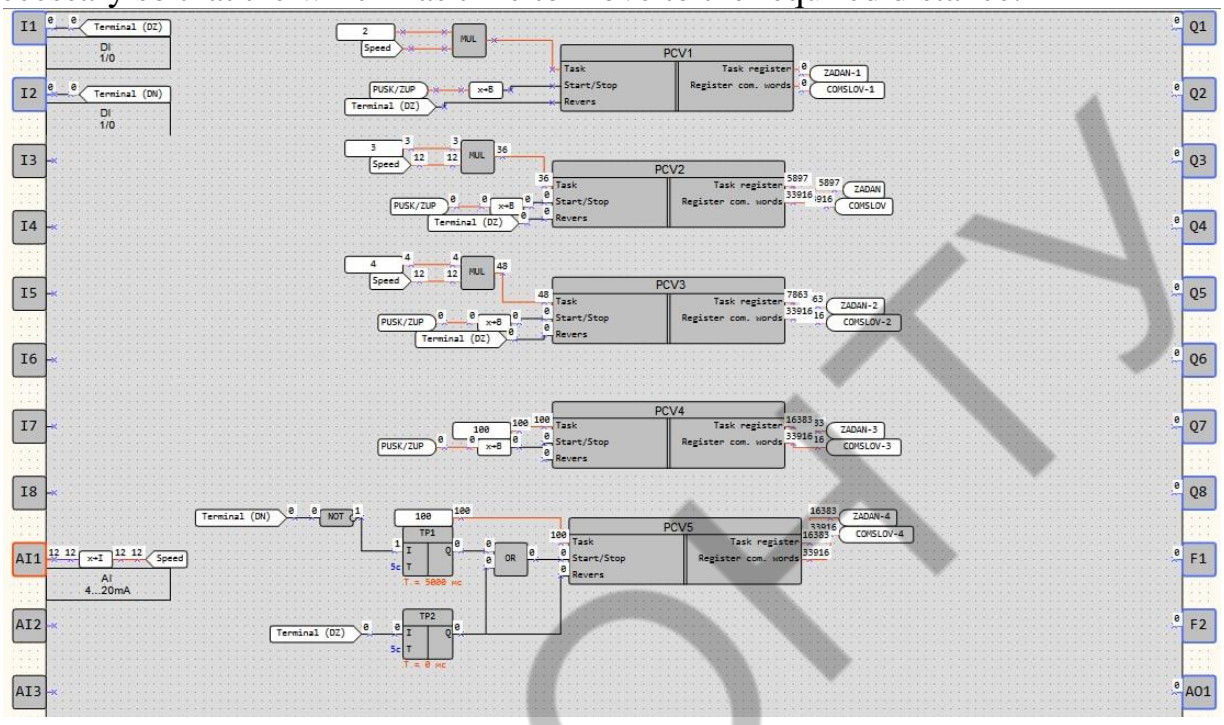


Fig. 5. Operation of the program when the signal is applied (AI1)

Figure 6 shows the debugged and simulated wagon loading program after a series of serviceability tests. The program worked stably, no errors were detected, and the obtained data satisfy the conditions of the algorithm of the entire scheme.

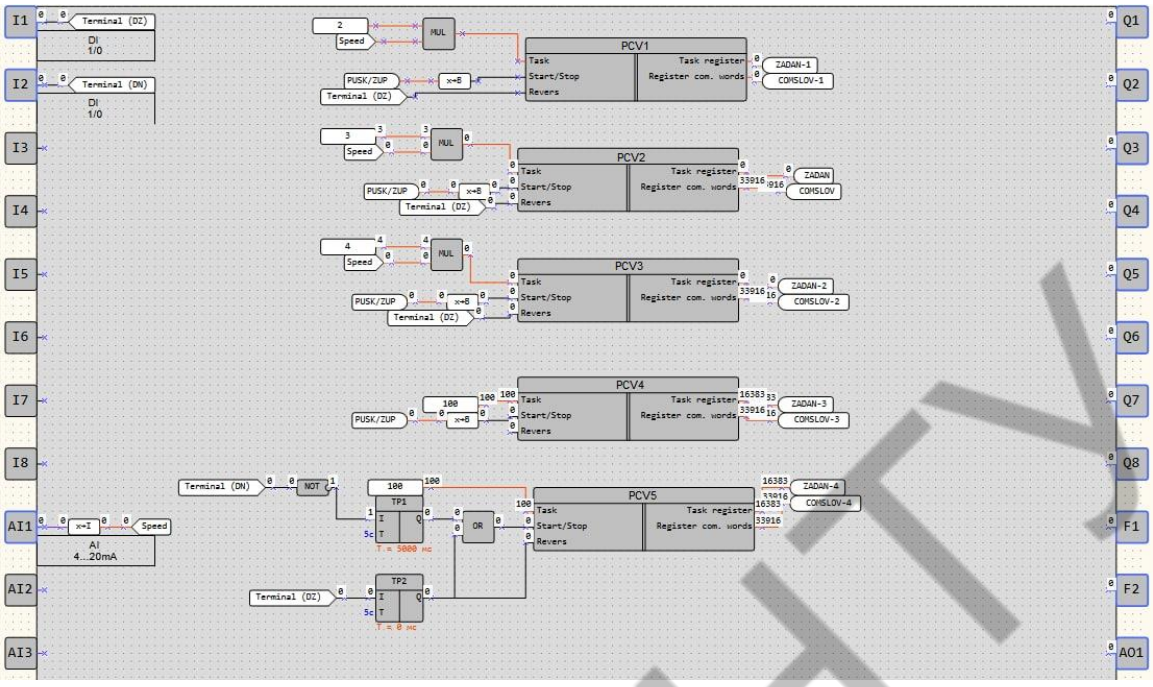


Fig. 6. The end of the program

V. CONCLUSIONS

A system of automatic control of the coal loading complex was developed and studied, which will be able to combine individual nodes into one common system to ensure greater control and reliability of the process. A modernized functional scheme of the SAC of the coal-loading complex was developed, and a set of hardware was selected for the technical implementation of the system. Algorithms for loading wagons for the local and main system under the control of a programmable relay and an industrial controller have been developed. A program based on modernized wagon loading algorithms was developed in the OwenLogic programming environment in the language of the MEK61131-3 standard.

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QR AND 3D TECHNOLOGIES INTEGRATION IN CHILDREN'S SAFETY PROJECTS

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Abstract. *The paper focuses on QR and 3D technologies that can be integrated in safety project. There have been analyzed different situations of children's missing in USA, Europe and Ukraine. Advantages of QR code using and its creation have been justified. There have been analyzed general properties of PLA plastic, its benefits and its harmlessness for the nature. 3D printing ease of use has been defined too. There have been described all elements of the developed product for children's safety. The database for QR code has been analyzed. Results of parents' poll according to the idea have been showed too. There has been analyzed situation about the interest in the developed product.*

Keywords: *3D printing, QR code, project, safety, accessory, children's missing, biodegradable PLA plastic*

I. INTRODUCTION

In the US, a child goes missing every forty seconds. About 840,000 children go missing every year, and the FBI estimates that 85-90% of them are children up to 12 years old. Most missing child reports are resolved within a few hours, but many involve situations where a child has been missing permanently or for an extended period of time [2].

Every two minutes a child goes missing in Europe. Missing Children Europe collects call statistics from twenty two "116,000 hotlines". In 2021, there were more than 54,655 calls about missing children, including 13% compared to the previous year. Let's describe the statistics. 57% of these cases are associated with running away from home, 26% of cases of parental abduction, 6% are associated with child migration phenomena, 2% are associated with lost or injured children and 8% of other types [14].

The protection of children is a priority for Renew Europe. Every year, thousands of children go missing. Although there is no statutory publication of statistics on missing children in the EU, some organizations estimate that 300,000 children disappear every year. This terrible situation cannot be allowed to continue.

With the illegal invasion of Ukraine by the Russian army, children are extremely vulnerable. According to UNICEF and UNHCR, over 100,000 unaccompanied minors have been forced to flee the conflict. They are at enormous risks.

Today, during martial law and other difficult situations in Ukraine, in particular, during the evacuation of children to other regions of Ukraine or abroad, children can go missing. Let's remember one situation, which photo was on all world newspapers (see Fig. 1).

Fig.1. Screen of international news about Vira Makovii

When the war began, a Ukrainian mother scrawled contact information on her daughter's back. On the first day of the war in Ukraine, the roar of bombs falling on the streets near Kyiv made it almost impossible to write a pen on my daughter's tiny, bare back, and it was necessary to write down the information. The result was a messy scrawl: Vira Makovij, 10.11.19 is the name and date of birth of her child. Two phone numbers followed, one is “Mama” (mother) and one is “Tato” (father) [15].

The mother narrated that she did so in the hope that if she died during the war and only Vera survived, someone would be able to connect Vera with her other surviving family members.

It was a hasty action. So this information could be erased from child’s back. Then nobody could help this little girl, because she didn’t talk. However, this problem arises not only during martial law, but also in everyday life situations.

The purpose of the study is developing unique accessories to help parents to find their missing children with the combining 3D printing and QR code technologies.

II. LITERATURE ANALYSIS

One of the main directions for development of Ukraine and other country is the sphere of ensuring the children’s safety. In last years issues of children safety have become an acute problem in our country. At the same time, the search for new approaches and technologies to the development of more effective projects to ensure the children’s safety of has been continued too.

Children's safety projects were carried out by different scients from Ukraine and other country [12, 7].

The actual problem of identification of young children who cannot identify themselves is existed. The approach for identifying children through a combination of QR code technology and 3D printing has been proposed.

Similar technologies are used in a digital pet ID tag. This tag has a QR code that links to the pet owners' contact details. Advantages of our technologies were described in the problem solving according existing approaches.

Special research methods - collection methods and generalization of information,

critical analysis and forecasting as well sociological survey methods and statistical data processing with the help of Microsoft Excel have been used.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

3.1. QR CODE TECHNOLOGY PROGRESS

The increasing of mobile Internet and portable devices have opened up a wide range of possibilities to the world. Nowadays QR codes using has become an integral part of everyday life and work. QR codes are found on places and items such as business cards, electronic devices, magazines, and T-shirts. A QR code (quick response code) is a type of barcode that is easily read by digital devices and stores information as a set of pixels in a square grid [9, 11].

The data stored in a quick response code can include website URLs, phone numbers, or text up to 4000 characters long. Abundantly smartphones have a built-in QR scanner, and some even have it built into the camera. QR Scanner is an easy way to scan QR codes. QR code scanning with the help of our device is very easy. Three simple steps must be made:

1) QR reader app or the camera on your smartphone must be opened.

2) The camera at the QR code must be pointed. The information you need, no matter what angle you point the camera at, can be got.

3) The data must be immediately displayed on the screen. For example, if the QR code contains contact information, your phone should download it immediately.

The QR code generation software does not collect personal information. The data it collects and shows to the creator of the code includes number and time the code, location was scanned, and the operating system of the device that scanned the code (for e.g. Android or iPhone) [9].

Although QR codes can serve many purposes, there are 4 widely accepted QR codes' versions. The data that is stored and is called the "input mode" is determined in your version. There are binary, numeric, kanji or alphanumeric. The type of mode is transmitted through information field version in the QR code [1].

Byte mode is used for characters from the ISO–8859–1 character set. It can store 2953 characters.

Numeric mode is decimal from 0 to 9. This mode is the most efficient storage mode, allowing you to store up to 7089 characters.

Kanji mode is for double-byte characters in the Shift JIS character set and is used to encode Japanese characters. It is an original mode that is pioneered by DENSO WAVE.

Although, it becomes the least efficient after that, saving only 1817 characters. The second kanji mode, called Extended Channel Interpretation (ECI) mode, allows you to specify the UTF-8 kanji character set. Although, some newer QR code readers cannot read this character set [9].

.Alphanumeric mode is used for decimal digitals from 0 to 9, plus uppercase letters from A to Z, and symbols +, –, ., $, %, *, : and / as well as a space. Everyone can store up to 4296 characters.

Two additional modification modes of the other types are too. Structured Append mode encodes data by multiple QR codes and can read up to 16 QR codes at the same time. FNC1 mode allows you to use QR codes as GS1 barcodes.

QR codes can store a lot of data, while they may look simple.

But no matter how much it contains, scanning a QR code should give the user immediate access to the information. That's why it's called a quick response code.

3.2. ADVANTAGES OF 3D PRINTING TECHNOLOGY

The QR Code, printed on the product packaging or the other paper goods, is difficult to read because the packaging material can be slightly wrinkled or uneven.

The advantage of printing a QR code on plastic is that its surface has gradation. It could be more useful to print QR code on some hard surfaces. It will help to scan this code without some mistakes.

The solution to this problem is to print a QR code on 3D things. Let’s describe all advantages of 3D printing. Additive manufacturing or 3D printing is the process of creating 3D solid objects from digital files [13]. 3D printing contrasts with subtractive manufacturing, where metals and plastics are milled [10].

The printing of 3D goods allows complex shapes to be created with less material than traditional manufacturing methods [4]. In its early days, the printing of 3D was only good for prototyping and one-off production, but now it is rapidly becoming a manufacturing method.

PLA plastic for 3D printing must be used for our experiment. PLA (polylactic acid) is more environmentally affable then other plastics. Because it's a biodegradable polymer base, it's much more environmentally friendly than conventional plastics like ABS, which aren't likely to degrade in the next 100 years or more [3].

It takes 500-1000 years for ABS plastic to completely decompose. This problematic nature of plastic has halted plastic researchers as large amounts of plastic are produced each year and some of it continues to end up in our waterways and oceans [3, 16].

PLA is a biocompatible, renewable, biodegradable and thermoplastic polyester derived primarily from corn starch. The monomeric lactic acid (LA) in polylactic acid (PLA) is derived from natural sources. Lactic acid is produced using bacterial fermentation of sugar cane, corn, potatoes and other biomass [5, 6]. Figure 2 shows the life cycle of PLA product.

Fig.2. Energy Modelling for FDM 3D Printing from a Life Cycle Perspective [8]

Polylactic acid is a very practical material to replace petroleum-based polymers due to its excellent mechanical properties and superior processability [5]. The general properties of PLA show the table 1. Polylactic acid provides several leads over other materials, including:

1) Easy to 3D printing;
2) Environmentally well (if disposed of correctly);
3) Reliable for applications such as medical equipment and food containers;
4) It comes with a wide range of composites and color options to offer different properties and looks.

TABLE I . GENERAL PROPERTIES OF PLA

Property	Value
Heat Deflection Temperature	126 ºF (52 ºC)
Impact Strength (Unnotched) IZOD (J/m)	96.1
Flexural Strength	80 MPa
Density	1.24 g/cm^2
Tensile Strength	50 MPa
Shrink Rate	037-041% (0/0037-0.0041 in/in)

Polylactic acid is popular for 3D printing because it is easy to sand, paint, and post-process. An easy-to-use material, this plastic works at low extrusion temperatures and does not require printer chambers, heated platforms or heavyduty nozzles. Another advantage is that polylactic acid behaves better than many tougher plastics and does not smoke or stink. It is easy to store, can be made in a variety of colors, and can be used as a base for various composites with additional properties [17]. Made from recyclable and renewable resources, polylactic acid has many benefits for the future. What's more, with the rise in oil prices, corn-based plastics also have economic benefits.

3D printing technologies can change almost every major industry and change the way of people life, job and entertainment in the future.

IV. RESULTS

Analyzing the situation about children's missing, measures for more children's safety must be taken immediately. It is proposed a unique accessory that has the QR code. QR code will include some information about parents, their phone numbers or some information about the child's illness. QR code will not contain the confident information (for e.g. about the child or parents). 3D accessory will consist of PLA plastic (that is biodegradable and decomposes totally in 12 years) and can have different design (see fig. 3 a, b).

Fig.3 (a). Unique accessory as MVP

Fig.3 (b). Unique accessory as MVP

Data Base includes the simple excel table or the simple Google's document with some information (see fig. 4).

G21 fx

	A	B
1	MOTHER	38050 65 56 65 5
2	FATHER	38095 59 95 55 9
3		
4	My NAME	Jack
5		
6		

Fig.4. Excel table with the information

If to talk about iPhones, there can be some problems with excel tables. So, Google's documents would be more useful in this case (see fig. 5). If to plan create data base with some another information (not only parents' numbers and etc.), it is used MySQL.

Fig.5. Google's document with the information for iPhones

Another advantage of our product is the material, which does not cause allergies in children, does not tear, unlike paper or fabric. The material of our product is PLA plastic. It is safe and fully biodegradable for 12 years.

The main advantages include fast child's identification and the communication possibility with his parents. The accessories include increased resistance to the influence of external factors and the possibility of restoring information, compared to printing with ink on paper or other materials. The information will be saved under the influence of destructive factors, such as high humidity, mechanical, thermal, chemical and other types of influence. This becomes especially relevant in the conditions of war.

The survey of 300 respondents, who are parents, was created. The next diagram shows the survey results (see fig. 6). 92 % of parents worried about the safety of their children. 74 % of parents were interested of our idea and our product. 21 % of parents wanted to use our product.

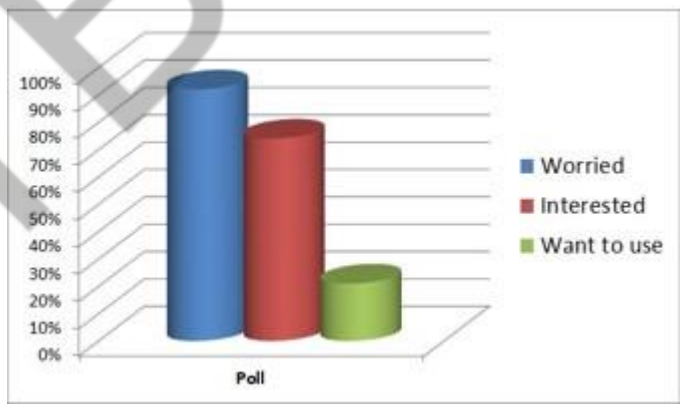

Fig.6. Results of parents' poll according to our idea

The next stage of our research was the presentation our product and its usefulness. It has been used "Facebook" where some posts about our product were prepared, than these posts were shared in different groups (local city groups, many mothers' groups etc.). "Tik Tok" with information about our product has been used. This social network helped to interest not only parents, but their children who wanted to have "cool" accessories and

to be different from others. This product in entertainment centers was presented too. Data analysis of various sources regarding public interest in our product is presented in fig. 7.

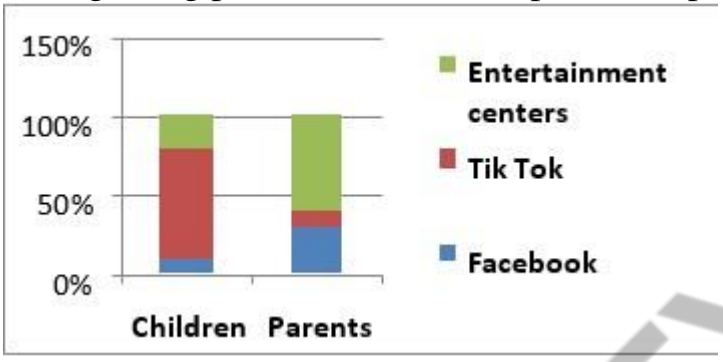

Fig.7. Results about the interest in our development

The results suggest that children are interested in using an accessory just to be fashionable. They didn't understand the importance of safety, because they are so little. Using "Tik Tok", entertainment centers and sometimes "Facebook", they asked to buy this accessory only for the entertainment.

But these results show that their parents are more interested in children's safety. And the best result of it is to present our development in entertainment centers, where it can be explained how it works and then it can be presented this accessory for some parents free.

To establish the interest of the authorities, a question about occupation was included in the survey (see fig. 8).

The results showed that 46% of people work in state structures (police, medicine, state emergency services). In this case, the interest of this category of the population in our product will allow us to bring information about solving the problem of children's missing to the authorities.

Fig.8. Results of questions about the occupation

The effectiveness of such measures will increase when this technology is integrated into child safety projects.

Our development provides integration to the children's safety projects. One of the components of these projects is training for actions in an emergency. This technique was described in the paper [12].

V. CONCLUSIONS

It has been established, that every 20 children go missing in Ukraine every day. And 1 child goes missing in Europe each 2 minutes a day. This sad statistic has been increasing every year. There is a need to provide emergency assistance to missing children.

The combination QR code and 3D printing technologies to create unique accessories that are useful and vital for children's safety have been proposed.

The QR code will not contain confidential information. In special cases, the information can be expanded and can include the blood group or the need to use special drugs (for example, insulin).

It has been established that PLA is the optimal material for printing accessories. Polylactic acid is more environmentally well then other plastics. It is safe and fully biodegradable for 12 years.

The advantage of printing a QR code on plastic is that its surface has gradation, unlike paper, which can be damaged. QR code will include the information about parents, their phone numbers or some information about the child's illness.

It is predicted that our development will be of interest to many parents around the world and can be useful in the security system of local communities, police, medicine and other emergency services.

Future research can be dedicated to development and implementation of the difficult Database, that will include information about insurance policy, child's illness and blood group or some another information. The database will include a privacy feature that will be accessible by medical, police and emergency services. This can help improve safety and save the lives of more children.

The proposed QR code and 3D printing technology will contribute to increasing the protection of children in emergencies, providing emergency medical care and quickly finding parents and relatives of lost children. The content of the information encoded in the QR code for different age groups of children, as well as the legislation of other countries, requires separate research.

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DEVELOPMENT OF MEANS FOR HIGH PRODUCTIVE RENDERING

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Abstract. *The analysis of the most common bidirectional functions of surface reflectance and methods of shading in realistic computer graphics has been conducted. The property of constancy of the increase of color intensity along the horizontal (vertical) rasterization lines of the triangle has been proved. Methods of parallelization of the computational process, new models of surface reflectivity and modification of the Gouraud method have been proposed. Shader programs based on the proposed methods have been developed and integrated into a professional graphics pipeline. A new device structure for determining the intensity of color is proposed.*

Keywords: *Gouraud shading, Phong shading, Blinn model, rendering, bidirectional reflectance distribution function, normal vector, surface reflectance, shader.*

I. INTRODUCTION

Relevance of the research topic. The role of computer graphics [1-10], as one of the main providing subsystems of computer technology is constantly growing, since it allows in the conditions of the modern level of development of computer technology to implement the most acceptable and familiar to the user technology of presenting information [1-3].

When synthesizing graphic scenes, it is necessary to solve a double problem - ensuring high realism of graphic objects and achieving an acceptable time for a specific task to form graphic scenes.

Three-dimensional images are realistic if they reproduce the most significant aspects of a process or phenomenon, convey the constructive, visual and visual features of objects. For the realistic formation of graphic images, it is necessary to adequately reproduce the shape and color of surfaces.

Today, the performance of graphic tools does not fully meet the needs of various branches of three-dimensional graphics.

In this regard, the urgent task is to increase the realism and productivity of the formation of images of three-dimensional scenes by developing new methods and means that would simplify the visualization procedures both at the software and hardware levels.

Scientific novelty of the results

1. The property of the constancy of the increase in color intensity along the horizontal (vertical) rows of rasterization of the triangle has been proved, which made it possible to increase the productivity of shading due to the fact that the increase in color intensity is calculated for the triangle, and not for each of its rasterization lines. This made it possible on average to reduce the shading time of the average triangle by an average of 1.7 times and simplify the hardware implementation.

2. Based on the proven property of the constancy of color intensity increase, methods of parallelization of the computational process are proposed, which provide an increase in shading performance with a balanced load of renders.

3. New models of surface reflectivity are proposed, which differ from the existing ones by the absence of an elevation operation to the power, and in relation to the well-known Schlick BRDF – the absence of division operation, the presence of only basic addition and multiplication operations, which makes it possible to develop devices with a relatively simple hardware implementation. The proposed BRDF have a second and third degree.

3. A modification of the Gouraud method is proposed, which consists in determining the maximum values of color intensities on the edges of a triangle, followed by the division of the triangle into components, which makes it possible to reproduce the specular highlights that cross the edges of the triangle and, as a result, increase the realism of the formation of the graphic scene.

The practical value of the work:

1. Shader applications have been developed and integrated into a professional graphic pipeline. Experimental evaluations for the developed methods were obtained.

2. A new device structure for determining the intensity of color is proposed.

Implementation. The work was implemented in the company 3D GENERATION UA, 2021. Result of implementation: methods and software.

Publication. 7 scientific works were published on the subject of research. Including: 6 – in the materials of the International Conferences of the Conference, 1 – certificate of copyright registration for a computer program.

II. LITERATURE ANALYSIS

The general formula for calculating the reflected energy brightness from point *x* of the surface of the object in the $\vec{\omega}_o$ direction using bidirectional reflectance distribution function (BRDF) is as follows [1-3, 8]:

$$L_o(x,\vec{\omega}_o) = \int_{\Omega 2\pi} f_r(\vec{\omega}_o,\vec{\omega}_i)\cdot L(x,\vec{\omega}_i)\cdot(\vec{\omega}_i \bullet \vec{n})\, d\vec{\omega}_i, \quad (1)$$

where f_r – BRDF, $\vec{\omega}_i$ – the vector of the beam of light fall direction, $L(x,\vec{\omega}_i)$ – the energy brightness, coming in the $\vec{\omega}_i$ direction, $(\vec{\omega}_i \bullet \vec{n})$ – the scalar product of the vector $\vec{\omega}_i$ and the normal of the surface $\vec{n}$. Input data for the calculation of BRDF are shown in Fig. 1.1.

Phong BRDF [1-4, 6] became the first empirically model for calculating the specular highlight. To calculate the intensity of specularly reflected light according to the Phong model, three parameters are used: the vector of the reflected beam direction $\vec{R}$, the vector to the observer direction $\vec{V}$ and the specular coefficient *n*. In the presence of such data, the calculation of the specular component of the surface color is carried out as follows:

$$f_r(\omega_i,\omega_o) = (\vec{R} \bullet \vec{V}). \quad (2)$$

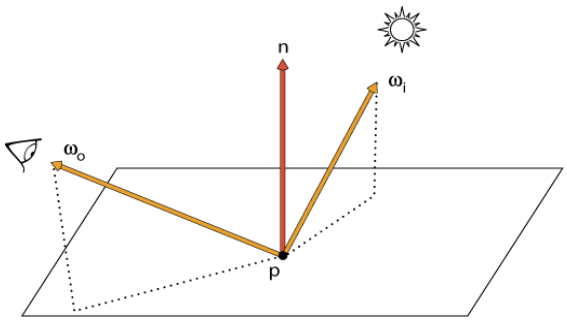


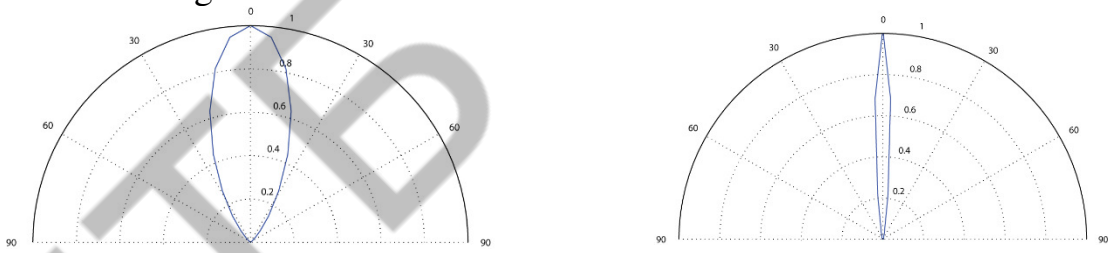
Fig. 1. Input data for the calculation of BRDF

Fig. 1 shows images of two spheres for visualization of which Phong (specular reflection) model was used.

a) b)

Fig.1. Visualization using the Phong model at: a) n=15, b) *n*=75

Fig. 3 shows the distribution of the values of the Phong BRDF depending on the magnitude of the angle between the vectors $\vec{R}$ and $\vec{V}$.



a) b)

Fig.2. Phong's BRDF value depending on the angle between vectors $\hat{R}$ and $\hat{V}$ at: a) n=10, b) *n*=75

The main disadvantage of Phong BRDF [1-4] and other empirical BRDF is that the resulting distribution of specular highlight intensity (Fig. 3) differs significantly from the experimental data obtained as a result of the study of the reflectivity of real materials using a gonioreflectometer. This leads to the fact that the visualization of the surface, which in its properties of scattering incident light resembles real-life materials (metals, dielectrics), using the Phong model is impossible. When using Phong BRDF, the value of the specular coefficient $n \in [1;1000]$. This causes its high computational complexity, which negatively affects the rendering performance of an object that uses such BRDF.

D. Blinn [1-4, 7, 8] proposed to use in the Phong BRDF the value of the cosine of the angle not between vectors $\vec{R}$ and $\vec{V}$, but between the normal $\vec{N}$ and the half-way vector $\vec{H}$, which is equal to $\left(\vec{L}+\vec{V}\right)/\left|\vec{L}+\vec{V}\right|$, where $\vec{L}$ is the beam of light incidence direction [3]. The resulting BRDF was called the Blinn model and has the following form:

$$f_{r_s}(\omega_i,\omega_o)=(\vec{H}\bullet\vec{N})^n. \quad (3)$$

In this form, Blinn BRDF has an additional definition as a function of the distribution of the normals of microfacets of the surface of a three-dimensional object, and the parameter *n* in its context acquires a physical value – the standard deviation of the normals of microfacet from the $\vec{H}$ direction.

If the Blinn function [1-4] is used as a function of the distribution of normal microfacets, the normalization coefficient $\frac{n+2}{2\pi}$ must be entered into the formula (2), the presence of which ensures the equality of the visible area of microfacets to the surface area on which they are located [1].

The use of an $\vec{N}\bullet\vec{H}$ operand also causes a change in the shape of the surface reflection at the limiting angles of light incidence. For convex surfaces, the shape of the specular highlight does not actually differ in the calculation according to the Phong and Blinn models, but the specular highlight on flat surfaces in the case of limiting angles of light incidence differ significantly. The difference in the reflection of specular highlight by Phong and Blinn models described above is shown in Fig. 4.

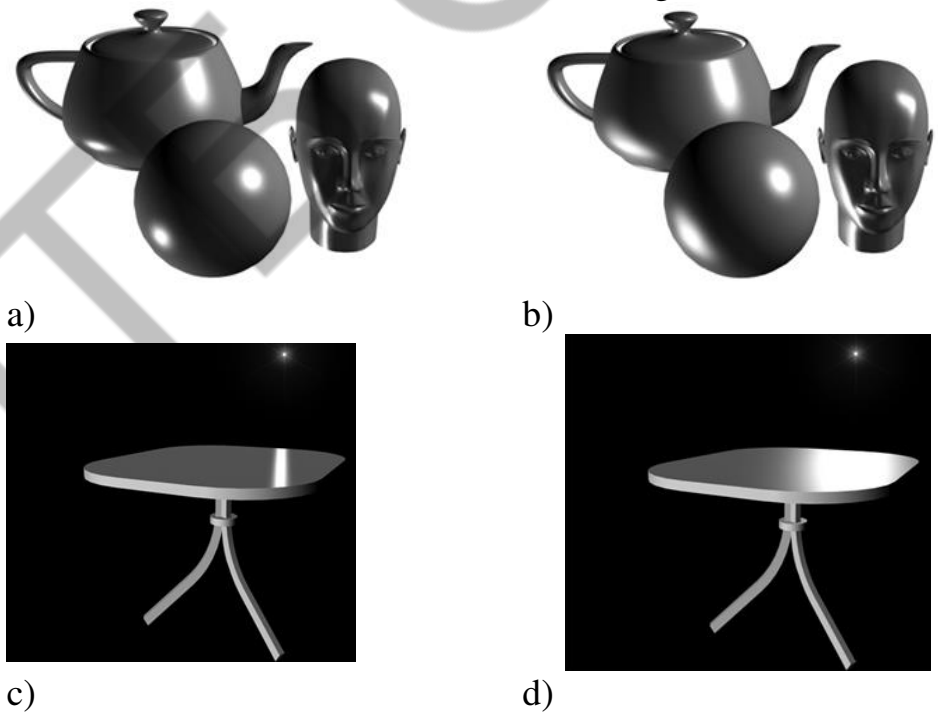


Fig.4. Visualization of specular highlight in the case of: a) convex surfaces and Blinn model, b) convex surfaces and Phong models, c) flat surfaces and Blinn model, d) flat surfaces and Phong model

This feature of specular highlight visualization when light falls at a limiting angle allows to reproduce the specular scattering of light on flat surfaces more realistically. Fig.5 shows images with specular reflection of light from relatively flat surfaces.

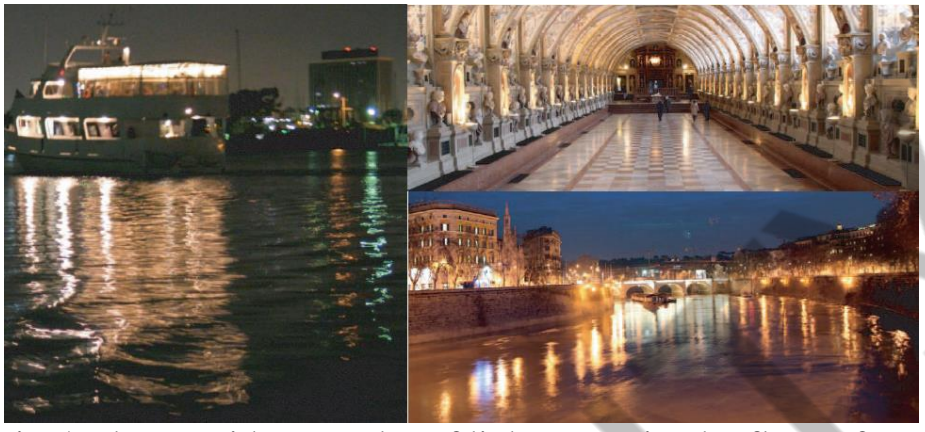


Fig.5. Photos with examples of light scattering by flat surfaces

From fig.5, it can be seen that in a real environment, specular highlight from flat surfaces has a oblong shape, and therefore Blinn BRDF, through the use of a half-way vector, provides a more realistic reproduction of such specular highlight than the Phong model.

At the same time, the use of other vectors did not solve the problem of high computational complexity due to the presence of an exponentiation operation.

To reduce the computational complexity of the Phong and Blinn BRDF by eliminating the operation of elevation to the power, it is possible to use Schlick BRDF [1, 4]:

$$f_{r_s}(\omega_i, \omega_o) = \frac{(\vec{H} \bullet \vec{N})}{n - n(\vec{H} \bullet \vec{N}) + (\vec{H} \bullet \vec{N})}. \quad (4)$$

A significant disadvantage of Schlick BRDF is that the distributive function in the bluming zone drops to zero extremely slowly, as demonstrated in Fig.6, which causes unnatural lighting of the graphic object and additional calculations by increasing the interval of changing the argument.

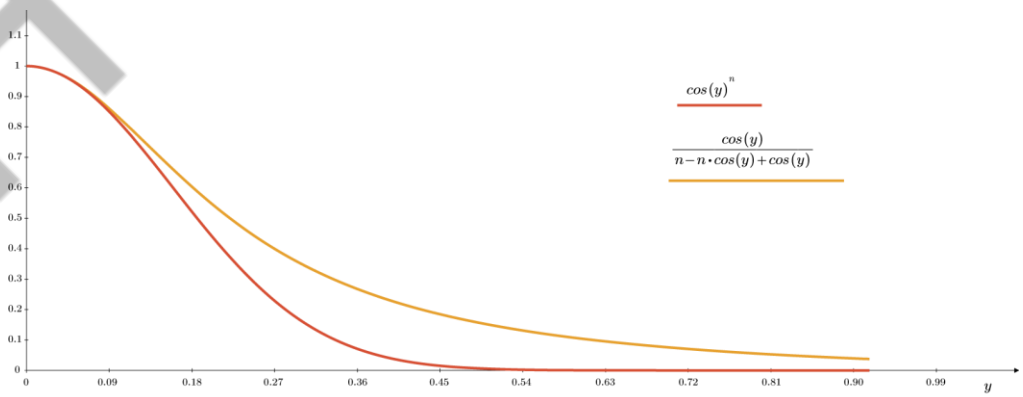


Fig.6. Graphs of the Blinn and Schlick functions for n = 40

To visualize materials like bronze, copper, nickel, it is necessary to take into account the Fresnelian reflection of light and the change in the color of the specular highlight depending on the angle of light incidence. Such phenomena are taken into account when calculating the intensity of the specular color of the surface using the Cook-Torrance BRDF. According to the Cook-Torrance model, the value of the specular component of the color is calculated as follows [1]:

$$f_{r_s}(\omega_i, \omega_o) = \frac{FDG}{\pi(\vec{N} \bullet \vec{L})(\vec{N} \bullet \vec{V})}, \quad (5)$$

where F is the coefficient that determines the Fresnelian reflection of light, D is the distribution function of the normals of the microfacets of the surface, G is the coefficient of geometric overlap of microfacets. Calculating the coefficients F, G and D requires significant computational resources.

Despite the presence of models like the Cook-Torrance BRDF, which take into account the characteristic features of light scattering by metals, modern computer graphics still actively use Phong and Blinn models, especially if there is only an integrated type of GPU. Graphics adapters used in mobile phones, tablets and laptops belong to the class of video cards designed for embedded systems [7] and have significantly less computing power than graphics adapters.

The use of Phong and Blinn models is also relevant in the editors of three-dimensional scenes for shading objects in a scene at the stage of its layout.

Given the relevance of using the Blinn and Phong BRDF, the author chose Blinn BRDF as a prototype to create a more efficient BRDF with a similar form of specular highlight.

The most common methods of shading include the Gouraud method [1-4, 9], which provides an acceptable compromise between the speed of formation of three-dimensional images and their quality. The shading process has the following stages: a) calculate the vectors of the normals to each face; b) by averaging the normals of all faces to which the vertex belongs, the normals at the vertices of the triangle (polygon) are calculated; c) determine the intensity of color at the vertices of the polygon using the values of the normals; e) paint over an area bounded by a polygon by linear interpolation of color intensities along the edges, and then between the edges along each rasterization line. Recently, shading according to Gouraud has often been used as an intermediate stage in the interactive formation of a 3D image, putting the construction of a full-fledged scene at the stage of final rendering.

The disadvantages of the Gouraud method include: a) the method uses linear interpolation to determine the intensity of color, while the diffuse and specular components of color have a nonlinear nature of change; b) the local curvature of the surface is not taken into account, since the vectors of the normals are determined only for the vertices of the triangle; c) specular highlight is reproduced only if the vertices of the triangles are in their zone (a specular highlight that does not have common points with

the vertices of the triangles, or is located inside the triangle, is not formed); d) on the boundaries of two triangles, Mach bands appear [3], which are associated with literal inhibition on the retina; e) there is a change in the intensity of the image color from frame to frame, which is expressed in flashing, especially specular highlight, since during the formation of dynamic images the structure and position of the nodes of the triangulation mesh changes; g) the presence of an artifact of the "star" type, which consists in the fact that the specular highlight, which should have the shape of an ellipse, has the shape of a star. This is explained by the fact that areas of specular highlight are formed in different triangles and the effect of Mach bands appeared; g) the method does not take into account the perspective of the object.

Although the Gouraud method continues to be widely used to form three-dimensional images in real time, the Phong method [1-4, 5, 10] is considered more promising, in which normal vectors are interpolated instead of color intensity values, which are then used in the toning function to calculate the color intensity of each image element. The method is characterized, compared to the Gouraud method, by much higher computational costs, but at the same time a better local approximation of surface curvature is achieved and, as a result, more realistic images are obtained. In recent years the works on the use of Phong shading intensified especially.

In most cases, when shading according to Phong, Blinn and Phong lighting models are used [3]. This is because the indicated BRDF are derived from the cosine of the angle between vectors, which are easily found due to their scalar product. When the light source and observer are located at a sufficiently large distance from the object (the most common case in computer graphics), the $\vec{H}$ vector for the Blinn model is calculated once for each triangle.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The purpose and objectives of the research. The aim of the work is to increase the productivity and realism of the formation of three-dimensional graphic images through the development of new methods and means.

The object of the research is the process of shading three-dimensional graphic objects.

The subject of the research is methods and means of shading three-dimensional graphic objects.

Research methods. In the work there were used: the theory of differential calculus, analytical geometry, number theory for the development of shading methods; theory of algorithms for the development of programs for shading and normalization of vectors; computer modeling to test theoretical statements.

IV. ORGANIZATION OF THE COMPUTATIONAL PROCESS OF HIGH-PRODUCTIVE RENDERING

4.1. Property of constancy of the increase in color intensity along the horizontal (vertical) rasterization lines of the triangle

When developing methods and means of shading, it is important to establish such functional relationships between the output parameters that will significantly simplify the implementation of rendering both at the software and hardware levels.

Definition. The rasterization line of a triangle (RLT) is the space between its edges in one of the orthogonal directions.

Statement. With linear interpolation of color intensities along edges and triangle rasterization lines, the increase in color intensity along horizontal (vertical) rasterization lines is constant.

Proof. Let the triangle ABC be given by the coordinates of its vertices (X_A, Y_A), (X_B, Y_B), (X_C, Y_C) and their corresponding color intensities: I_A, I_B, I_C. Let`s pass through the vertex B a segment BK (Fig.7), which is parallel to the abscissa axis. We get two triangles – ABK and BKC.

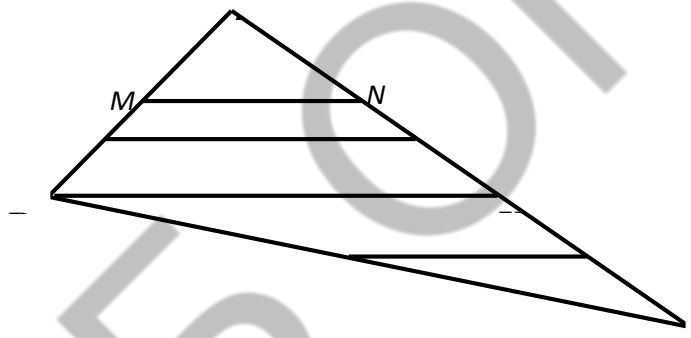


Fig.7. Rasterization lines of the triangle

Let's find increments in color intensities for arbitrarily selected rasterization strings FG and MN:

$$\Delta I_{MN} = \frac{I_N - I_M}{MN}, \quad \Delta I_{FG} = \frac{I_G - I_F}{FG} \quad . \tag{6}$$

Express the intensity of the color of the points G and F through the intensity of the color of the vertices $A, B\ i\ C$: $I_G = \frac{I_C - I_A}{AC} \cdot AG + I_A$, $I_F = \frac{I_B - I_A}{AB} \cdot AF + I_A$.

Substitute the value of I_G, I_F into the formula (6). Then we obtain

$$\Delta I_{FG} = \frac{I_C - I_A}{AC} \cdot \frac{AG}{FG} - \frac{I_B - I_A}{AB} \cdot \frac{AF}{FG}. \tag{7}$$

Similarly, for points *M* and *N,* write

$$I_N = \frac{I_C - I_A}{AC} \cdot AN + I_A, \; I_M = \frac{I_B - I_A}{AB} \cdot AM + I_A.$$

Find the increase in color intensity along the rasterization line MN

$$\Delta I_{MN} = \frac{I_C - I_A}{AC} \cdot \frac{AN}{MN} - \frac{I_B - I_A}{AB} \cdot \frac{AM}{MN}. \quad (8)$$

Triangles AFG and AMN similar, since their corresponding angles are equal. From the similarity of triangles it follows that

$$\frac{AG}{FG} = \frac{AN}{MN}, \quad \frac{AF}{FG} = \frac{AM}{MN}. \quad (9)$$

Given the ratio (9), it can be stated that the right parts of the expressions (7) and (8) coincide, i.e. $\Delta I_{FG} = \Delta I_{MN} = \Delta I_g$.

Since the triangle ABK is similar to the triangle AFG, then $\Delta I_{BK} = \Delta I_{FG}$.

Similarly, it can be shown that for an arbitrary RLT WV of triangle BKC $\Delta I_{WV} = \Delta I_{BK}$. Since the triangles ABK and BKC have a common line BK, it can be argued that the resulting property takes place for the entire triangle.

Thus, the increase in intensity is a constant value for all horizontal rasterization lines. Obviously, increments in color intensities have constant values for vertical rasterization lines as well.

The proven property can significantly reduce the volume of calculations during the implementation of shading, since the increase in color intensity is determined for the entire triangle, and not for each line of rasterization. This allows to perform these calculations in the preparation cycle and eliminate "long" operations directly from the shading cycle.

The analysis showed that compared to the classical implementation, a reduction in shading time by 1.7 times is achieved.

Increments in color intensities for adjacent triangles have different meanings, therefore, due to the discrete nature of the formation of step trajectories of the edges of the polygon, an artifact violation of the monotony of the change in color intensity within neighboring polygons is possible.

Find expressions for calculating intensity increments along horizontal and vertical rasterization lines. To do this, make a system of equations

$$\begin{cases} I_B = I_A + \Delta I_v \cdot \Delta Y_{BA} - \Delta I_g \cdot \Delta X_{AB}, \\ I_C = I_A + \Delta I_v \cdot \Delta Y_{CA} - \Delta I_g \cdot \Delta X_{CA}. \end{cases}$$

Solving a system of equations with respect to I_g, I_v, we obtain

$$\Delta I_g = \frac{\Delta X_{AB} \cdot (I_A - I_C) + \Delta X_{CA} \cdot (I_A - I_B)}{\Delta X_{AB} \cdot \Delta Y_{CA} - \Delta X_{BA} \cdot \Delta X_{CA}}, \quad \Delta I_v = \frac{\Delta Y_{CA} \cdot (I_B - I_A) + \Delta Y_{BA} \cdot (I_A - I_C)}{\Delta X_{AB} \cdot \Delta Y_{CA} - \Delta X_{BA} \cdot \Delta X_{CA}}.$$

The diagonal step can be considered as the simultaneous execution of vertical and horizontal step movement, therefore, for edges with positive coordinate increments

$$\Delta I_{dg} = \frac{(\Delta X_{AB} + \Delta Y_{BA}) \cdot (I_A - I_C) + (\Delta X_{CA} - \Delta Y_{CA}) \cdot (I_A - I_B)}{\Delta X_{AB} \cdot \Delta Y_{CA} - \Delta X_{BA} \cdot \Delta X_{CA}}.$$

In other cases, it is necessary to take into account the signs of increments of coordinates.

The proven property of constancy of color intensity increase can also be used for vectors, replacing the intensity of color with a coordinate component. It can be argued that the increments of orthogonal coordinate constituent vectors of normals [10] along horizontal (vertical) RLT have constant values. That is, for normal vectors along horizontal (vertical) lines $\Delta x = const,\ \Delta y = const,\ \Delta z = const$, where $\Delta x,\ \Delta y,\ \Delta z$ are the differences between the corresponding coordinate components of the two adjacent vectors in the rasterization line.

To normalize the normal vector at the starting point of the rasterization line of the triangle, use the formula

$$\vec{N} = \frac{x}{\sqrt{x^2 + y^2 + z^2}}\vec{i} + \frac{y}{\sqrt{x^2 + y^2 + z^2}}\vec{j} + \frac{z}{\sqrt{x^2 + y^2 + z^2}}\vec{k}.$$

For the normal vector following it, the sub-root expression will look like this

$$F_i = (x + \Delta x)^2 + (y + \Delta y)^2 + (z + \Delta z)^2 =$$

$$= (x^2 + y^2 + z^2) + 2 \cdot (x \cdot \Delta x + y \cdot \Delta y + z \cdot \Delta z) + ((\Delta x)^2 + (\Delta y)^2 + (\Delta z)^2).$$

Introduce the notation

$$A = x^2 + y^2 + z^2\ ,\ \ B = (x \cdot \Delta x + y \cdot \Delta y + z \cdot \Delta z),\ C = (\Delta x)^2 + (\Delta y)^2 + (\Delta z)^2.$$

For i-vector relative to the first vector in the rasterization line $F_i = A + 2 \cdot i \cdot B + i^2 \cdot D$. Use the finite difference method for the last member [1], for which find

$$\Delta_1 = (i + 1)^2 \cdot D - i^2 \cdot D = 2 \cdot i \cdot D + D,$$

$$\Delta_2 = 2 \cdot (i + 1) \cdot D + D - 2 \cdot i \cdot D - D = 2 \cdot D.$$

Taking into account the resulting expressions, write

$F_{i+1} = F_i + 2 \cdot B + C_{i+1}$, where $C_{i+1} = C_i + 2 \cdot D$, $C_1 = D,\ F_o = A,\ C_0 = 1$.

The obtained formulas for calculating the sub-root expression do not have multiplication operations.

The proven property of constancy of the increase in color intensity along the RLT can be used to parallelize the shading.

4.2. Methods of parallelization of the shading procedure

The first method is based on the distribution of computational actions of the shading procedure at the lower level, when the geometric processor is given the parameters of comparable triangles, as well as the intensity of color at their vertices. The shading of the area bounded by a triangle is carried out using Sierpinski triangulation. According to the method, the triangle is divided into four comparable by connecting the middle of its sides. The result is four triangles that are equal in area. Comparable triangles are shaded over in parallel. In this case, only one shading device is used, which tones one of the triangles, and the results of its work are transferred to all other triangles with a

certain displacement in coordinates and corresponding transformations of the color intensity of the points. Due to the parallelization of the computational process, the original triangle will be shaded 4 times faster.

When shading, rasterization of the upper triangle is performed and all elementary step increments for other triangles are repeated, taking into account the fact that triangles 1, 2, 3 have the same shading directions, and triangle 4 is shaded in the opposite direction (Fig. 8). Before rasterization, the coordinates of the vertices of all comparable triangles are found. Similarly, when determining the intensity of color of the inner points of the upper (left) comparable triangle, all actions of code interpolation are duplicated for other comparable triangles, but with respect to their vertices.

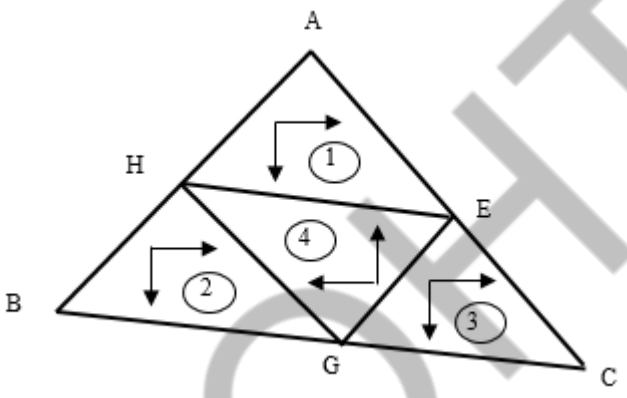


Fig.8. Shading of the triangles

Since the triangulation of the original triangle is carried out by dividing its edges in half, the problem arises of such a division of the triangle into comparable ones, at which there will be no "cut" points, since the increments of the sides of the original triangle are not always even.

One of the methods of parallelization is the independent determination of color intensities at even and odd points of the rasterization line (Fig. 9, a), which provides an increase in the productivity of shading up to two times. In the preparation cycle, the color intensities I_1, I_2 are found, respectively for the first and subsequent points in the rasterization line. The color intensities of the following points in the RLT are found by the formulas:

$$I_4 = I_2 + 2\Delta I_g,\ I_6 = I_4 + 2\Delta I_g,\ \ ...,\ ...;\ I_{2w} = I_{2w-2} + 2\Delta I_g,$$
$$I_3 = I_1 + 2\Delta I_g,\ I_5 = I_3 + 2\Delta I_g,\ \ ...,\ ....\ I_{2w+1} = I_{2w-1} + 2\Delta I_g,$$

Since the increase in color intensity along the rasterization line is constant, the intensity of the color at its i point can be determined by the formula $I_i = I_1 + i \cdot \Delta I_\Gamma$, which allows to independently determine the intensity of the color of the whole segment of points (Fig. 9, b) in the rasterization line. The simplest hardware implementation of the method takes place with segment sizes that are multiples of the power of two.

With segmental implementation, color intensity increases are determined for all

points in the segment and the color intensity of the first point of the next segment. When forming the last segment due to masking, the recording in the video memory of those points that go beyond the rasterization line is blocked.

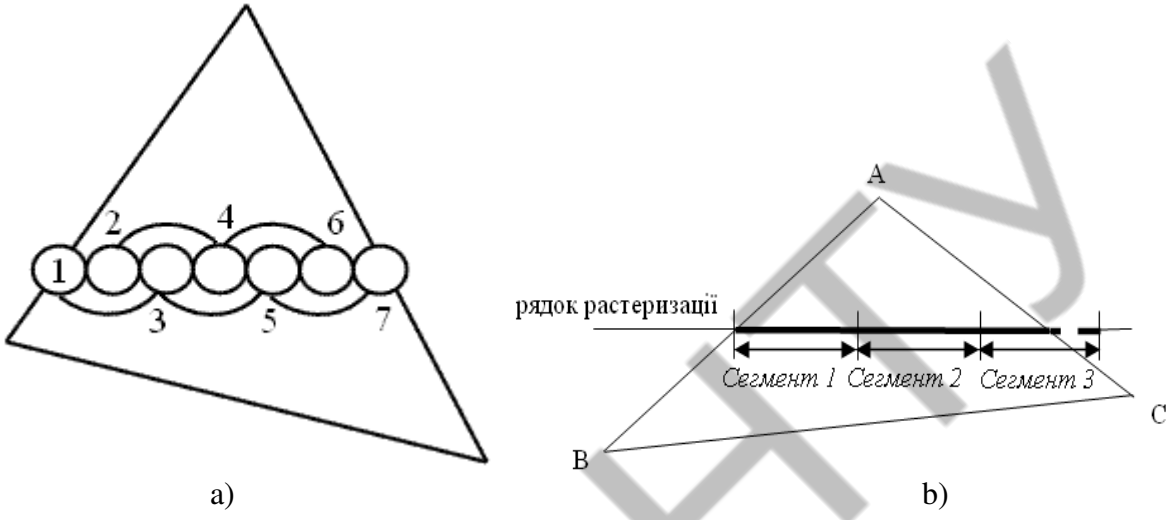


Fig.9. Methods of parallelization: a) shading over even and odd points in a rasterization line of a triangle; b) separating the rasterization line into segments

4.3. Polynomial approximation of BRDF

Consider the approximation of the BRDF by quadratic function with respect to $cos\gamma$, which has the following form

$$cos^n\gamma = a\cdot cos^2\gamma + b\cdot cos\gamma + c. \qquad (10)$$

To find unknown coefficients, use points $a,\ b,\ c$ whose BRDF values can be easily determined.

If $\gamma = 0 \quad cos^n\gamma = 1$, then

$$a + b + c = 1. \qquad (11)$$

If $cos\gamma = 0$, then $cos^n\gamma = 0$. Therefore

$$a\cdot 0 + b\cdot 0 + c = 0. \qquad (12)$$

From the formulas (11) and (12) find that

$$c = 0; \quad b = 1 - a. \qquad (13)$$

To find the coefficient a, equate the value of the BRDF and the quadratic function at the inflection point of the function $cos^n\gamma$. The abscissa of this point is $\vartheta = arctg(\frac{1}{\sqrt{n-1}})$ [3] . Taking into account (10) and (13), write

$$a\cdot cos^2\vartheta + (1-a)\cdot cos\vartheta = cos^n\vartheta.$$

Introduce the following notation $t = cos\vartheta,\ \ t^n = cos^n\vartheta$. Then the previous formula

will have the form: $a \cdot t^2 + (1-a) \cdot t = t^n$. From the last equation find that $a = (t^{n-1} - 1)/(t-1)$. Taking into account the values t and ϑ write the formula for determining the coefficient a

$$a = \frac{\cos^{n-1}(\operatorname{arctg}(\frac{1}{\sqrt{n-1}})) - 1}{\cos(\operatorname{arctg}(\frac{1}{\sqrt{n-1}})) - 1}.$$

It is advisable to pre-calculate the values of a and store them in memory.

The maximum value of a is 786.4. Up to the inflection point of the BRDF, the maximum relative approximation error does not exceed 3.14 %, and the maximum absolute error does not exceed 0.025. When the accuracy of approximation is not subject to strict requirements, the value of the coefficient a can be determined by the approximation formula $a = 0{,}786 \cdot n$ with a relative error less than 0.3% for all $21 \le n \le 1000$. For the remaining range the relative error does not exceed 4%.

In determining the coefficient a, other levels of the distribution function can be used. For example, when using an ordinate level equal to *0.5*, the maximum approximation error of the distributive function $\cos^n \gamma$ will increase to 6%, but the specular highlight attenuation zone will be better reproduced.

In the case when the level q is selected to determine the coefficient a, then

$$a = \frac{\cos^{n-1}(\exp(\frac{\ln(q)}{n})) - 1}{\cos(\operatorname{arctg}(\exp(\frac{\ln(q)}{n}))) - 1}.$$

Characteristic features of the approximation of BRDF with a polynomial of the second power:

a) it is sufficient to determine only two coefficients – a and b;

b) due to a sharp decrease of the approximating function when it approaches the zero level, the specular highlight has a visually noticeable boundary, which is typical for materials with a high specular coefficient;

c) by selecting the level of BRDF to determine the coefficient a, it is possible to control the error of reproduction of the epicenter of the specular highlight and its attenuation zone;

d) since the new BRDF takes a negative value, it is necessary to provide for the cutting off of the function at the boundary of the transition through the zero level.

Consider the approximation of the BRDF $\cos(\gamma)^n$ by function $f_1(x)$, which has the form

$$f_1(\gamma) = a_1 \cdot \cos(\gamma)^3 + b_1 \cdot \cos(\gamma)^2 + c_1 \cdot \cos(\gamma) + d_1.$$

Let's find the unknown a_1, b_1, c_1, d_1. To do this, it is needed to make a system of four equations. Taking into account that $\cos(0)=1$, get $a_1 + b_1 + c_1 + d_1 = 1$, $\cos(\gamma)=0$

when $d_1 = 0$. Equating the value of the BRDF and the cubic polynomial at the point t, where $cos(t)^n = Q$, find that

$$a_1 \cdot cos^3(t) + b_1 \cdot cos^2(t) + c_1 \cdot cos(t) + d_1 = Q.$$

The last equation of the system to find the unknowns a_1, b_1, c_1, d_1 can be obtained by equating the derivatives of the BRDF and the proposed cubic polynomial at the point t where $cos(t)^n = Q$.

$$\frac{\partial(cos^n \gamma)}{\partial \gamma} = -n \cdot cos(\gamma)^{n-1} \cdot sin(\gamma).$$

$$f(\gamma)' = -3 \cdot a_1 \cdot cos(\gamma)^2 \cdot sin(\lambda) - 2 \cdot b_1 \cdot cos(\gamma) \cdot sin(\gamma) - c_1 \cdot sin(\gamma).$$

Let's equate the right parts of the last two expressions and divide them into $-sin(t)$ Get

$$n \cdot cos(t)^{n-1} = 3 \cdot a_1 \cdot cos(t)^2 + 2 \cdot b_1 \cdot cos(t) + c_1.$$

To find the coefficients of the cubic multimember $f_1(\gamma)$, reduce the obtained equations into a system of equations

$$\begin{cases} a_1 + b_1 + c_1 + d_1 = 1, \\ d_1 = 0, \\ a_1 \cdot cos^3(t) + b_1 \cdot cos^2(t) + c_1 \cdot cos(t) + d_1 = Q, \\ n \cdot cos^{n-1}(t) = 3 \cdot a_1 \cdot cos^2(t) + 2 \cdot b_1 \cdot cos(t) + c_1. \end{cases}$$

After equivalent transformations, obtain a system of two equations:

$$\begin{cases} a_1 \cdot cos^3(t) + b_1 \cdot cos^2(t) + (1 - a_1 - b_1) \cdot cos(t) = Q, \\ 3 \cdot a_1 \cdot cos^2(t) + 2 \cdot b_1 \cdot cos(t) + (1 - a_1 - b_1) = n \cdot cos^{n-1}(t). \end{cases}$$

The solution of the resulting system of equations is as follows:

$$a_1 = \frac{n \cdot cos^n(t)(cos(t) - 1) - Q \cdot (2 \cdot cos(t) - 1) + cos^2(t)}{cos^2(t) \cdot (cos(t) - 1)^2},$$

$$b_1 = \frac{n \cdot cos^n(t)(1 - cos^2(t)) + Q \cdot (3 \cdot cos^2(t) - 1) - 2 \cdot cos^3(t)}{cos^2(t) \cdot (cos(t) - 1)^2}.$$

If choose $Q = 0,5$, then

$$a_1 = \frac{(q-1)(2q+n)+1}{2 \cdot (q-1)^2 \cdot q^2}, b_1 = -\frac{q^2(4q-3) + n(q^2-1) + 1}{2 \cdot (q-1)^2 \cdot q^2},$$

where $q = e^{\frac{-0.6931471}{n}}$.

Using a cubic polynomial to reproduce the epicenter of the specular highlight provides sufficiently high accuracy (Fig.10). The simulation showed that for the most common range, the maximum relative error in the approximation of the epicenter of the

specular highlight does not exceed 0.67%. Compared to the Schlick distribution function [3] at this interval, the maximum relative approximation error is reduced by more than 17 times. $\left(\forall \boldsymbol{n} \in [1;256]\right)$.

Fig.10. Three-dimensional figures visualized using BRDF of the third power

4.3. Hardware implementation of the shading device using the developed BRDF

In this paper, a new BRDF is proposed using a second-power polynomial, the calculation of which involves the use of operations that are simple from a computational point of view, which allows it to be implemented by hardware. Fig. 11 shows the block diagram of the device. The peculiarity of the structure is the usage only one coefficient, the value of which determines all the others.

The device (Fig.11) includes registers $RG1-RG5$, block of permanent memory $PROM$, multiplication blocks $MUL1-MUL5$, block of inverters BI, combination adders $Sm1$-$Sm2$. The value n of the specular coefficient is written in the register $RG1$ and the cosine value of the angle between the normal vector and the vector $\vec{H}$ is written in the register $RG2$. The registers $RG3$- $RG5$ store the intensity values of R, G, B components of the color of the light source respectively, multiplied by k_s. For each value n the corresponding values of coefficient a are stored in the $PROM$ block. The value $\cos\gamma$ from the output of register $RG2$ is fed to both inputs of the multiplication block $MUL1$, which ensures the formation at its output $\cos^2\gamma$. At the output of the block BI an inverse value of $\cos\gamma$ is formed, which enters the information input of the adder $Sm1$, at the output of which the operand $\cos^2\gamma-\cos\gamma$ is obtained. In the adder $Sm1$ subtraction operation is conducted in supplementary code, therefore the level of the logical unit is given to its transfer input. At the output of $MUL2$ the product $a\cdot(\cos^2\gamma-\cos\gamma)$ is formed that goes to the information input of the adder $Sm2$. At the output of the adder $Sm2$, the value of the BRDF is formed, which is equal to $a\cdot(\cos^2\gamma-\cos\gamma)+\cos\gamma$. From the output of the adder $Sm2$, the value of the BRDF is fed to the first inputs of the multiplication blocks $MUL3-MUL5$, at the outputs of which the intensities of the specular component of the color for each channel are formed.

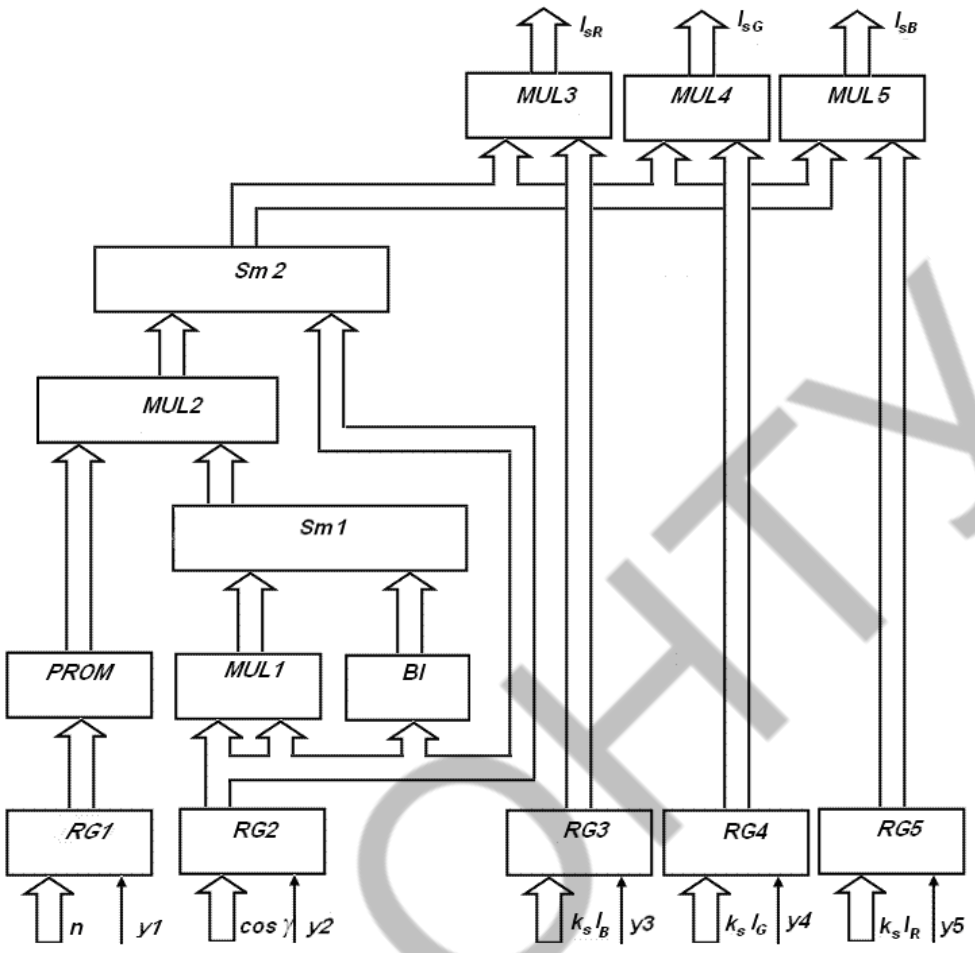


Fig.11. Block diagram of the device for determination of the specular component of color using BRDF of type $a \cdot cos^2 \gamma + b \cdot cos \gamma + c$

4.4. Modification of the Gouraud method

The most common methods of shading include the Gouraud method [3, 9], which provides an acceptable compromise between the speed of formation of three-dimensional images and their quality. The shading process has the following stages [3,8]: a) calculate the vectors of the normals to each face; b) by averaging the normals of all faces to which the vertex belongs, the normals at the vertices of the triangle (polygon) are calculated; c) determine the intensity of color at the vertices of the polygon using the values of the normals; e) shading over an area bounded by a polygon by linear interpolation of color intensities along the edges, and then between the edges along each rasterization line.

The most significant drawback of the Gouraud method is that the specular highlights that cross the edges of the triangle will not be reproduced.

The author proposes a method that eliminates this drawback.

The normal vectors to the points of the edge *AB* can be found from the parametric equation $\vec{N}_i^{AB} = \vec{N}_A + t_1 \cdot (\vec{N}_B - \vec{N}_A)$. Let's normalize the vector $\vec{N}_i^{AB}$ (Fig. 12).

$$\frac{\vec{N}_i^{AB}}{\left|\vec{N}_i^{AB}\right|} = \frac{\vec{N}_A + t_1 \cdot (\vec{N}_B - \vec{N}_A)}{\sqrt{(\vec{N}_A)^2 + 2 \cdot t_1 \cdot \vec{N}_A \cdot (\vec{N}_B - \vec{N}_A) + t_1^2 \cdot (\vec{N}_B - \vec{N}_A)^2}}.$$

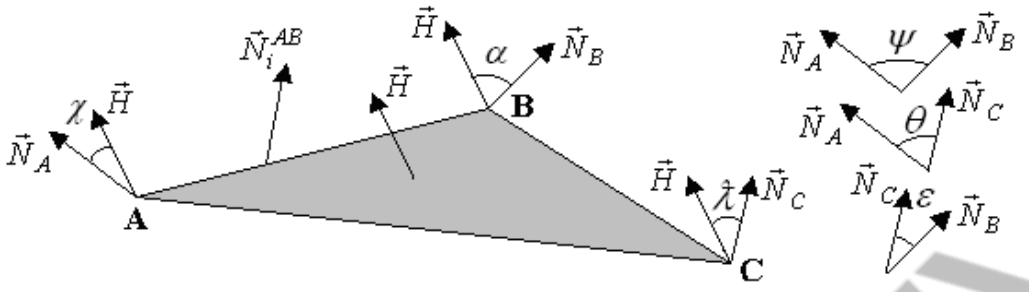


Fig.12. Normal vectors of the triangle ABC

Since $\vec{N}_A$, $\vec{N}_B$ are unit, then $\vec{N}_A^2 = \vec{N}_B^2 = 1$. Taking into account the latter, as well as the fact that $\vec{N}_A \cdot \vec{N}_B = cos\psi$, find

$$\frac{\vec{N}_i^{AB}}{\left|\vec{N}_i^{AB}\right|} = \frac{\vec{N}_A + t_1 \cdot (\vec{N}_B - \vec{N}_A)}{\sqrt{2 \cdot t_1^2 \cdot (1 - cos\psi) - 2 \cdot t_1 \cdot (1 - cos\psi) + 1}}.$$

Find positions on the edges of the triangle *ABC*, where the specular highlight is the most intense. The above can be judged by the value of the cosine of the angle between the vector $\vec{H}$ and the unit vectors of the normals to the points of the edges.

So, for example, for the edge *AB*

$$\frac{\vec{N}_i^{AB} \cdot \vec{H}}{\left|\vec{N}_i^{AB}\right|} = \frac{(\vec{N}_A + t_1 \cdot (\vec{N}_B - \vec{N}_A)) \cdot \vec{H}}{\sqrt{2t_1^2 (1 - cos\psi) - 2t_1 (1 - cos\psi) + 1}} = \frac{cos\chi + t_1 (cos\alpha - cos\chi)}{\sqrt{2t_1^2 (1 - cos\psi) - 2t_1 (1 - cos\psi) + 1}},$$

where χ, α are the angles between the vector $\vec{H}$ and the vectors $\vec{N}_A, \vec{N}_B$ respectively.

In the above expression, all quantities are scalar.

Let's find t_1, in which the scalar component of the color on the edge *AB* has the maximum value. To do this, find the derivative of the previous expression and equate it to zero.

$$\left(\frac{\vec{N}_i^{AB} \cdot \vec{H}}{\left|\vec{N}_i^{AB}\right|}\right)' = \frac{t_1 (1 - cos\psi) \cdot (cos\alpha - cos\chi) - cos\chi \cdot cos\psi + cos\alpha}{(2t_1^2 (1 - cos\psi) - 2t_1 (1 - cos\psi) + 1)^{3/2}} = 0.$$

The last equation has a root

$$t_1 = \frac{cos\chi \cdot cos\psi - cos\alpha}{(cos\psi - 1)(cos\alpha + cos\chi)}. \qquad (14)$$

Similarly, for the edges *AC* and *BC*, the values of the parameters t_2, t_3, at which the maximum value of the specular component of the color is achieved, respectively are equal to

$$t_2 = \frac{\cos\chi \cdot \cos\theta - \cos\hat{\lambda}}{(\cos\theta - 1)(\cos\hat{\lambda} + \cos\chi)}, \quad t_3 = \frac{\cos\alpha \cdot \cos\varepsilon - \cos\hat{\lambda}}{(\cos\varepsilon - 1)(\cos\hat{\lambda} + \cos\alpha)}. \qquad (15)$$

By value t, it is easy to find coordinates x, y on the edges of a triangle, where the specular component of the color is maximum. So, for example, for the edge AB

$$x = \lceil x_A + t_1 \cdot (x_B - x_A) \rceil, \quad y = \lceil y_A + t_1 \cdot (y_B - y_A) \rceil.$$

When determining the diffuse component of a color, a vector $\vec{L}$ is used instead of a vector $\vec{H}$.

The shading process according to the developed approach contains: calculation of the points on the edges that intersect with the specular highlight zone, where the maximum value of the scalar product of the normalized normal vector and vector $\vec{H}$ takes place; calculation of the coordinates of points on the edge, where there is the greatest value of the specular component of the color; comparison of the obtained value of color intensity with the limit and making a decision on taking into account the specular component of the color; calculation of color intensity at predetermined points; dividing the original triangle into components; shading of the obtained triangles according to the Gouraud method.

The original triangle can be divided into several depending on the maximum values of color intensities at the points t_1, t_2, t_3. If all three values of color intensities are greater than the threshold, then the triangle is divided into four components (Fig. 13,a). In the case when only one of the points t_1, t_2, t_3 reaches the value of color intensities greater than the threshold, the triangle is divided into two components (Fig. 13,b). If the maximum values of the specular component of the color on the edges of the triangle are greater than the threshold value at only two points, then the triangle can be divided into three components as shown in Fig.13, c, d. In the latter case, at the point D, which divides the segment AC in half, it is easy to find the value of color intensity as the average value of color intensities at points A and C.

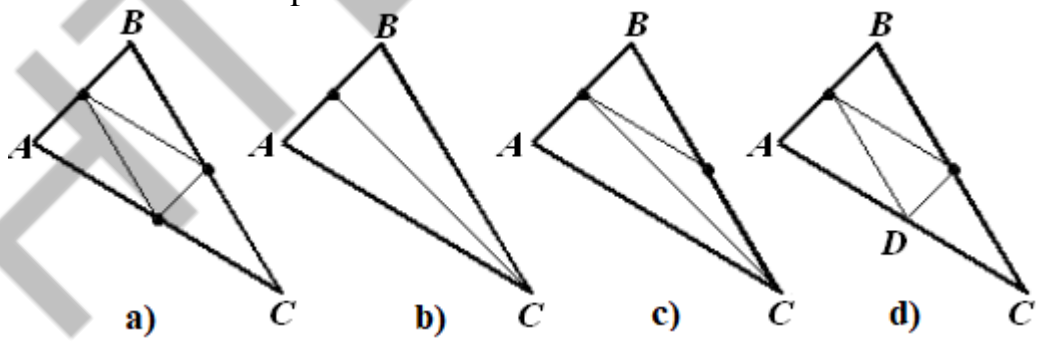


Fig. 13. Dividing a triangle into components

4.5. Software implementation

There has been developed a computer program (see listing, Appendix B) (Fig. 14) based on an open professional pipeline for modeling and testing proposed methods.

For the development of the software product, the Java programming language was chosen, the implementation of which is adapted to different platforms (the most famous of them are Win32, Unix/x86, Unix/Alpha, Solaris/Sparc, MacOS). A large number of libraries have been developed for the Java language, which greatly simplifies the development of software products. The advantage of the Java language is that the software module with an interface based on Swing or AWT can be easily adapted for use as a Java applet, which makes it possible to use the software module directly from the Internet browser.

The software module is built on the basis of the idx3d library, which has basic functions for working with 3D models and three-dimensional geometry. The object-oriented model of the software module is shown in Fig. 15.

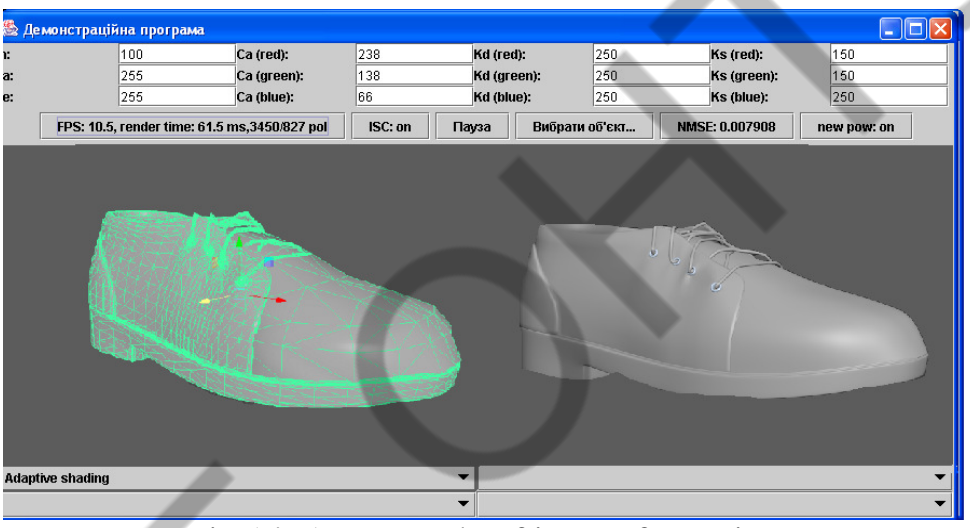


Fig.14. An example of image formation

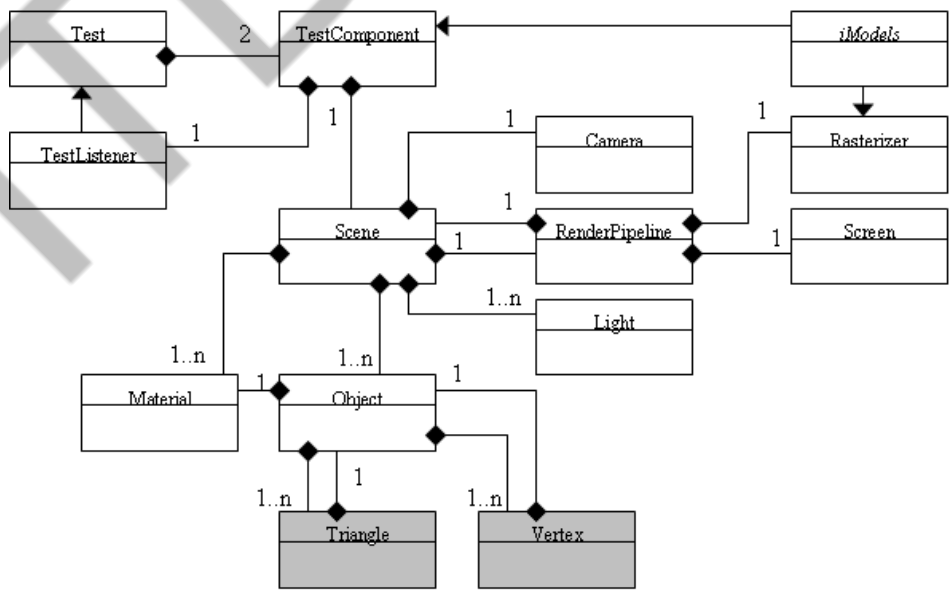


Fig. 15. Object-oriented model of the software module

Fig. 16 shows one of the examples of images, formed by using proposed methods.

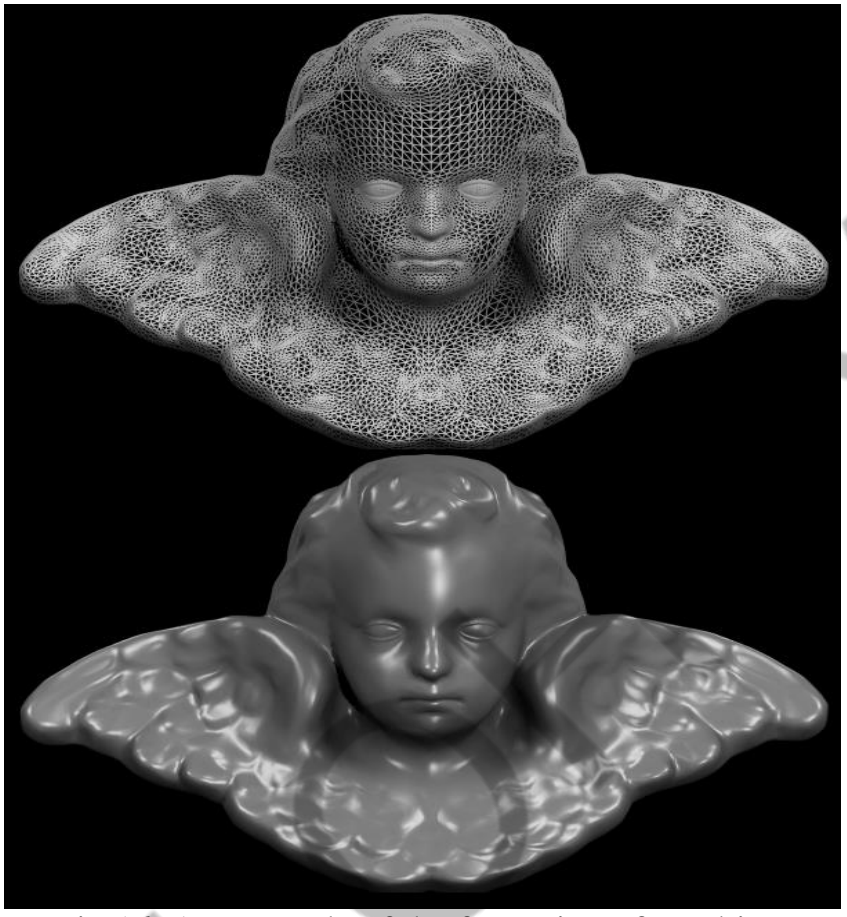


Fig.16. An example of the formation of an object

The simulation using the developed program confirmed the reliability of the obtained theoretical statements.

V. CONCLUSIONS

In the course of the work, the following results were obtained:

1. The analysis of the most common bidirectional functions of surface reflectance in realistic computer graphics has been conducted. The need to develop new models of surface reflectivity, which, unlike the existing ones, provided less computational complexity, simplicity of hardware implementation and reproduction of color intensities on the surface of the object within the limits that determine the visual identity with the reference image, is substantiated. The methods of shading are analyzed.

2. The property of constancy of the increase of color intensity along the horizontal (vertical) rasterization lines of the triangle has been proved, which made it possible to increase the productivity of shading due to the fact that the increase in color intensity is calculated for the triangle, and not for each of its rasterization lines. This made it possible on average to reduce the shading time of the average triangle by an average of 1.7 times and simplify the hardware implementation.

3. Based on the proven property of constancy of the increase of color intensity, methods of parallelization of the computational process are proposed, which provide an increase in shading performance with a balanced load of renders.

4. New models of surface reflectivity are proposed, which differ from the existing ones by the absence of an elevation operation to the power, and in relation to the well-known Schlick BRDF – the absence of a division operation, the presence of only basic addition and multiplication operations, which makes it possible to develop devices with a relatively simple hardware implementation. The proposed BRDFs have a second and third degree.

5. A modification of the Gouraud method is proposed, which consists in determining the maximum values of color intensities on the edges of a triangle, followed by the division of the triangle into components, which makes it possible to reproduce the specular highlights that intersect the edges of the triangle.

Practical value of the work: Shader programs have been developed and integrated into a professional graphics pipeline. A new device structure for determining the intensity of color is proposed.

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APPENDIX A

Директор ТОВ «3Д ДЖЕНЕРАЙШН ЮЕЙ»

Швець О.В

«20» грудня 2021 р.

АКТ

впровадження результатів студентської наукової роботи

Комісія у складі: директора Швеця О.В., технічного директора Чехместрука Р.Ю. та інженера-розробника Перуна І.В. склали цей акт про те, що у ТОВ «3д Дженерайшн Юей» впроваджено матеріали студентської наукової роботи на тему « Розробка моделі відбивної здатності поверхні, методів і апаратних засобів для високопродуктивного зафарбовування тривимірних графічних сцен ».

У ТОВ «3д Дженерайшн Юей» впроваджено нові моделі відбивної здатності поверхні, модифікацію метода Гуро.

Використання результатів студентської наувої роботи дозволило підвищити реалістичність та продуктивність формування тривимірних зображень.

[redacted] передано в ТОВ «3д Дженерайшн Юей» програмне забезпечення для формування тривимірних зображень.

Члени комісії Швець О.В.

Чехместук Р.Ю.

Перун І.В.

APPENDIX B

LISTING OF SOFTWARE MODULES

LISTING OF THE AdaptivGourauAndPhong module.java

```
public class AdaptivGourauAndPhong extends idx3d_Rasterizer
{
   private boolean bTypeRasterizer=false; true - Guoro, false - Phong.
   private double m12, m13, m23;
   private double q_1, q_2, q_3;
   private double p_1, p_2, p_3;
   private double opt_m=0.9;
   private double opt_q=0.004;
   private double opt_p=0.008;
   private idx3d_Vector h;
   int i1, i2, i3;
   float ii12r, ii12g, ii12b;
   float ii13r, ii13g, ii13b;
   float ii23r, ii23g, ii23b;
   float liir, liig, liib;
   float riir, riig, riib;
   float lir, lig, lib;
   float rir, rig, rib;
   float i4r, i4g, i4b;
   End for Gouraund
   for Phong
   private idx3d_Vector v4;
   private idx3d_Vector vi13, vi12, vi23;
   private idx3d_Vector lvi, rvi;
   private idx3d_Vector lv, rv;
   End for Phong
   public boolean selectMetod()
   {
      m12=p1.n.x*p2.n.x+p1.n.y*p2.n.y+p1.n.z*p2.n.z;
      m13=p1.n.x*p3.n.x+p1.n.y*p3.n.y+p1.n.z*p3.n.z;
      m23=p2.n.x*p3.n.x+p2.n.y*p3.n.y+p2.n.z*p3.n.z;
      if(Math.abs(m12)>opt_m ||
           Math.abs(m13)>opt_m ||
           Math.abs(m23)>opt_m) return false;
      else
      {
        h = idx3d_Vector.add(scene.light[0].v, scene.defaultCamera.lookat);
         q_1=p1.n.x*h.x+p1.n.y*h.y+p1.n.z*h.z;
         q_2=p2.n.x*h.x+p2.n.y*h.y+p2.n.z*h.z;
         q_3=p3.n.x*h.x+p3.n.y*h.y+p3.n.z*h.z;
         if(Math.abs(q_1-q_2)>opt_q ||
              Math.abs(q_1-q_3)>opt_q ||
              Math.abs(q_2-q_3)>opt_q) return false;
         else
         {

p_1=p1.n.x*scene.light[0].v.x+p1.n.y*scene.light[0].v.y+p1.n.z*scene.light[0].v.z;

p_2=p2.n.x*scene.light[0].v.x+p2.n.y*scene.light[0].v.y+p2.n.z*scene.light[0].v.z;

p_3=p3.n.x*scene.light[0].v.x+p3.n.y*scene.light[0].v.y+p3.n.z*scene.light[0].v.z;
            if(Math.abs(p_1-p_2)>opt_p ||
               Math.abs(p_1-p_3)>opt_p ||
               Math.abs(p_2-p_3)>opt_p) return false;
            else return true;
         }
      }
      return true;
   }
   public AdaptivGourauAndPhong()
   {
   }
   protected void initRender()
   {
      bTypeRasterizer=selectMetod();
    if(bTypeRasterizer)
    {
      for Gouraund
      h = idx3d_Vector.add(scene.light[0].v, scene.defaultCamera.lookat);
      int dy12 = Math.abs(p1.y-p2.y);
      int dy13 = Math.abs(p3.y-p1.y);
      int dy23 = Math.abs(p3.y-p2.y);
      i1 = calcColor(p1.n2);
      i2 = calcColor(p2.n2);
      i3 = calcColor(p3.n2);
      if (dy12 != 0)
      {
         ii12r = ((float)(idx3d_Color.getRed(i2) - idx3d_Color.getRed(i1))) / (float)dy12;
         ii12g = ((float)(idx3d_Color.getGreen(i2) - idx3d_Color.getGreen(i1))) / (float)dy12;
         ii12b = ((float)(idx3d_Color.getBlue(i2) - idx3d_Color.getBlue(i1))) / (float)dy12;
      }
      if (dy13 != 0)
      {
         ii13r = ((float)(idx3d_Color.getRed(i3) - idx3d_Color.getRed(i1))) / (float)dy13;
         ii13g = ((float)(idx3d_Color.getGreen(i3) - idx3d_Color.getGreen(i1))) / (float)dy13;
         ii13b = ((float)(idx3d_Color.getBlue(i3) - idx3d_Color.getBlue(i1))) / (float)dy13;
      }
      if (dy23 != 0)
      {
         ii23r = ((float)(idx3d_Color.getRed(i3) - idx3d_Color.getRed(i2))) / (float)dy23;
```

```
        ii23g = ((float)(idx3d_Color.getGreen(i3) -
idx3d_Color.getGreen(i2))) / (float)dy23;
        ii23b = ((float)(idx3d_Color.getBlue(i3) -
idx3d_Color.getBlue(i2))) / (float)dy23;
      }
      i4r = (dy12*ii13r) + idx3d_Color.getRed(i1);
      i4g = (dy12*ii13g) + idx3d_Color.getGreen(i1);
      i4b = (dy12*ii13b) + idx3d_Color.getBlue(i1);
      End for Gouraund
    }
    else
    {
      for Phong
       h = idx3d_Vector.add(scene.light[0].v,
scene.defaultCamera.lookat);
      int dx12 = Math.abs(p1.x-p2.x);
      int dx13 = Math.abs(p3.x-p1.x);
      int dx23 = Math.abs(p3.x-p2.x);
      int dy12 = Math.abs(p1.y - p2.y);
      int dy13 = Math.abs(p3.y - p1.y);
      int dy23 = Math.abs(p3.y - p2.y);
      vi13 = new idx3d_Vector((p3.n2.x - p1.n2.x) / dy13,
                        (p3.n2.y - p1.n2.y) / dy13,
                        (p3.n2.z - p1.n2.z) / dy13);
      vi12 = new idx3d_Vector((p2.n2.x - p1.n2.x) / dy12,
                        (p2.n2.y - p1.n2.y) / dy12,
                        (p2.n2.z - p1.n2.z) / dy12);
      vi23 = new idx3d_Vector((p3.n2.x - p2.n2.x) / dy23,
                        (p3.n2.y - p2.n2.y) / dy23,
                        (p3.n2.z - p2.n2.z) / dy23);
      v4 = idx3d_Vector.add(idx3d_Vector.scale(dy12,
vi13), p1.n2);
      End for Phong
    }
   }
   protected void prerenderFirstPart()
   {
    if(bTypeRasterizer)
    {
      for Gouraund
      lir = idx3d_Color.getRed(i1);
      lig = idx3d_Color.getGreen(i1);
      lib = idx3d_Color.getBlue(i1);
      rir = idx3d_Color.getRed(i1);
      rig = idx3d_Color.getGreen(i1);
      rib = idx3d_Color.getBlue(i1);
      if (dx > 0)
      {
        liir = ii12r;
        liig = ii12g;
        liib = ii12b;
        riir = ii13r;
        riig = ii13g;
        riib = ii13b;
      }
      else
      {
        riir = ii12r;
        riig = ii12g;
        riib = ii12b;
        liir = ii13r;
        liig = ii13g;
        liib = ii13b;
      }
      End for Gouraund
    }
      else
    {
      for Phong
      lv = p1.n2;
      rv = p1.n2;
      if (dx > 0)
      {
        lvi = vi12;
        rvi = vi13;
      }
      else
      {
        lvi = vi13;
        rvi = vi12;
      }
      End for Phong
    }
    }
    protected void prerenderSecondPart()
    {
     if(bTypeRasterizer)
     {
      for Gouraund
      if (dx > 0)
      {
        lir = idx3d_Color.getRed(i2);
        lig = idx3d_Color.getGreen(i2);
        lib = idx3d_Color.getBlue(i2);
        rir = i4r;
        rig = i4g;
        rib = i4b;
        liir = ii23r;
        liig = ii23g;
        liib = ii23b;
        riir = ii13r;
        riig = ii13g;
        riib = ii13b;
      }
      else
      {
        rir = idx3d_Color.getRed(i2);
        rig = idx3d_Color.getGreen(i2);
        rib = idx3d_Color.getBlue(i2);
        lir = i4r;
        lig = i4g;
        lib = i4b;
        riir = ii23r;
        riig = ii23g;
        riib = ii23b;
        liir = ii13r;
        liig = ii13g;
        liib = ii13b;
```

```
    }
    End for Gouraund
  }
  else
  {
    for Phong
    if (dx > 0)
    {
       lv = p2.n2;
       rv = v4;
       lvi = vi23;
       rvi = vi13;
    }
    else
    {
       lv = v4;
       rv = p2.n2;
       lvi = vi13;
       rvi = vi23;
    }
    End for Phong
  }
}
protected void prerenderLine()
{
  if(bTypeRasterizer)
  {
    for Gouraund
    renderLine();
    lir += liir;
    lig += liig;
    lib += liib;
    rir += riir;
    rig += riig;
    rib += riib;
    End for Gouraund
  }
  else
  {
    for Phong
    renderLine();
    lv = idx3d_Vector.add(lv, lvi);
    rv = idx3d_Vector.add(rv, rvi);
    End for Phong
  }
}
public String getRasterizerName()
{
    return "Adaptiv Gouraud And Phong";
}
protected void renderLine()
{
  if(bTypeRasterizer)
  {
    for Gouraund
    int cdx = xR - xL;
    if (cdx == 0) return;
    float iir = 0;
    float iig = 0;
    float iib = 0;
    float cir = 0;
    float cig = 0;
    float cib = 0;
    float lastr = lir;
    float lastg = lig;
    float lastb = lib;
    boolean bReset = true;
    for (x=xL;x<xR;x++)
    {
       pos=x+offset;
       if (z<zBuffer[pos])
       {
          if (rir==255 && rig==255 && rib==255 )
          {
             return;
          }
          if (bReset)
          {
             cdx = xR - x;
             if ((xR - x)>1)
             {
                iir = (rir - lir) / cdx;
                iig = (rig - lig) / cdx;
                iib = (rib - lib) / cdx;
                bReset = false;
             }
             cir = lir;
             cig = lig;
             cib = lib;
          }
          screen.p[pos]=0xFF000000                    |
idx3d_Color.getColor(Math.round(cir > 255 ? 255 : cir),
Math.round(cig > 255 ? 255 : cig), Math.round(cib > 255 ?
255: cib));
          screen.p[pos]=0xFF000000                    |
idx3d_Color.getColor(255, 255, 255);
          zBuffer[pos]=z;
          if (useIdBuffer) idBuffer[pos]=currentId;
          cir += iir;
          cig += iig;
          cib += iib;
       }
       else
          bReset = true;
    }
    z += dz;
    End for Gouraund
  }
  else
  {
    for Phong
    int cdx = xR - xL;
    if (cdx==0)
       return;
    for (int x=xL; x<xR; x++)
    {
       pos=x+offset;
       if (z<zBuffer[pos])
```

```
        {
          idx3d_Vector cv = idx3d_Vector.GetVectorOnPos(lv, rv, xL, xR, x);
          float angle = idx3d_Vector.angle(scene.light[0].v, cv);
          if (angle < 0) angle = 0;
          c = idx3d_Color.scale(color, (int)(angle*255));
          angle = idx3d_Vector.angle(h, cv);
          if (angle < 0) angle = 0;
          angle = (float)Math.pow(angle, n);
          int c2 = idx3d_Color.scale(0xFFFFFF, (int)(angle*255));
          c = idx3d_Color.add(c, c2);
          screen.p[pos]=0xFF000000|c;
          zBuffer[pos]=z;
          if (useIdBuffer) idBuffer[pos]=currentId;
        }
        z+=dz;
        nx+=dnx;
        ny+=dny;
      }
      End for Phong
    }
  }
  for Gouraund
  private int calcColor(idx3d_Vector vector)
  {
    float angle = idx3d_Vector.angle(scene.light[0].v, vector);
    if (angle < 0) angle = 0;
    int c = idx3d_Color.scale(color, (int)(angle*255));
    angle = idx3d_Vector.angle(h, vector);
    if (angle < 0) angle = 0;
    angle = (float)Math.pow(angle, n);

    int c2 = idx3d_Color.scale(0xFFFFFF, (int)(angle*255));
    c = idx3d_Color.add(c, c2);
    return c;
  }
  End for Gouraund
  protected void beforeRenderTriangle()
  {
  }
}
```

LISTING OF the NormalVector module.java

```
public class NormalVector extends idx3d_Rasterizer
{
  private idx3d_Vector h, v4;
  private idx3d_Vector vi13, vi12, vi23;
  private idx3d_Vector lvi, rvi;
  private idx3d_Vector lv, rv;
  int n_2;
  private idx3d_Vector N_2 ;
  int Nl,Nr, count_n;
  private idx3d_Vector dN_i,Na,Nb;
  private RET Ret[];
  public NormalVector()
  {
  }
  protected void initRender()
  {
    h = idx3d_Vector.add(scene.light[0].v, scene.defaultCamera.lookat);
    int dx12 = Math.abs(p1.x-p2.x);
    int dx13 = Math.abs(p3.x-p1.x);
    int dx23 = Math.abs(p3.x-p2.x);
    int dy12 = Math.abs(p1.y-p2.y);
    int dy13 = Math.abs(p3.y-p1.y);
    int dy23 = Math.abs(p3.y-p2.y);
    vi13 = new idx3d_Vector((p3.n2.x - p1.n2.x) / dy13,
                (p3.n2.y - p1.n2.y) / dy13,
                (p3.n2.z - p1.n2.z) / dy13);
    vi12 = new idx3d_Vector((p2.n2.x - p1.n2.x) / dy12,
                (p2.n2.y - p1.n2.y) / dy12,
                (p2.n2.z - p1.n2.z) / dy12);
    vi23 = new idx3d_Vector((p3.n2.x - p2.n2.x) / dy23,
                (p3.n2.y - p2.n2.y) / dy23,
                (p3.n2.z - p2.n2.z) / dy23);
    v4 = idx3d_Vector.add(idx3d_Vector.scale(dy12, vi13), p1.n2);
  }
  protected void prerenderFirstPart()
  {
    lv = p1.n2;
    rv = p1.n2;
    if (dx > 0)
    {
      lvi = vi12;
      rvi = vi13;
    }
    else
    {
      lvi = vi13;
      rvi = vi12;
    }
  }
  protected void prerenderSecondPart()
  {
    if (dx > 0)
    {
      lv = p2.n2;
      rv = v4;
      lvi = vi23;
      rvi = vi13;
    }
    else
    {
      lv = v4;
      rv = p2.n2;
      lvi = vi13;
      rvi = vi23;
    }
```

```
    }
    protected void prerenderLine()
    {
       norm();
       renderLine();
       lv = idx3d_Vector.add(lv, lvi); increment of vectors
horizontally in levo
       rv = idx3d_Vector.add(rv, rvi); increment of the
vector horizontally to the right
    }
     protected idx3d_Vector dN(int n, int k,idx3d_Vector
N_p,idx3d_Vector N_g )//for boundary irregular vectors
     {
      int n2=1, k2=1;
      n2<<=n;
      k2<<=k;
      idx3d_Vector Ngp= idx3d_Vector.sub(N_g,N_p);
      return new
idx3d_Vector((n2*Ngp.x/k2),(n2*Ngp.y/k2),(n2*Ngp.z/
k2));
     }
      protected void norm()
    {
       idx3d_Vector Nbuf12,N12;
       Na=lv; Nb=rv;
       int st=Math.abs(xR - xL);
       for(n_2=1;n_2<st;) // search for the number 2 in the
power of k
       {
        n_2<<=1;
       }
       if(st!=n_2)
       { //finding the finite vector
        idx3d_Vector buf= idx3d_Vector.sub(Nb,Na);
        N_2=new
idx3d_Vector((buf.x*n_2/st),(buf.y*n_2/st),(buf.z*n_2/st
));
         N_2.normalize();
         Nb=N_2;
       }
       double cos_W = idx3d_Vector.angle(Na,Nb);
       double z_12=Math.pow((2*(1+cos_W)),0.5);
       Nbuf12 = idx3d_Vector.add(Na,Nb);
       N12= new
idx3d_Vector((float)(Nbuf12.x/z_12),(float)(Nbuf12.y/z
_12),(float)(Nbuf12.z/z_12) );
N12.normalize();//middle
 double di=0;
       double zi=z_12;
       idx3d_Vector Ni=N12;
       Nl=xL;
       count_n=0;
       Ret=new RET[n_2];
       RET Wet= GetSegment( Na, Ni,Nb
,n_2/2,zi,n_2/2); search for intervals
       Ret[count_n]=Wet;
      for(int k=0;k<count_n;k++)
      {
       int min=n_2,point=0;
       for(int i=k;i<=count_n;i++)
       {
        int retx=Ret[i]. GetX();
        if(min>retx)
        {
           min=retx;
           point=i;
        }
       }
       RET buf= Ret[k];
       Ret[k]=Ret[point];
       Ret[point]=buf;
      }
      if(count_n>2)
       Ret[count_n+1]= new RET(Nb,n_2);
    }
    public RET GetSegment(idx3d_Vector
NA,idx3d_Vector Ni,idx3d_Vector NB , int n_2,double
zi,int R)
    {
         double di=1-(Math.pow((2+zi),0.5)/2); maximum
oshibka
         if(di<0.02 )
         {
          return new RET(Ni,R);
         }
         double zi1 = Math.pow((2+zi),0.5);
         idx3d_Vector  NLi= idx3d_Vector.add(NA,Ni);
         idx3d_Vector  Li=new
idx3d_Vector((float)(NLi.x/zi1),(float)(NLi.y/zi1),(float)
(NLi.z/zi1));
         idx3d_Vector  NRi= idx3d_Vector.add(NB,Ni);
         idx3d_Vector  Ri=new
idx3d_Vector((float)(NRi.x/zi1),(float)(NRi.y/zi1),(float)
(NRi.z/zi1));
          int dN=n_2/2;
         if(dN>=2)
          {
           Ret[count_n++]= GetSegment(NA, Li,Ni , dN,
zi1,R-dN);//vlevo
           Ret[count_n++]=GetSegment(Ni, Ri,NB , dN,
zi1,R+dN);//right
          }
      return new RET(Ni,R);
    }
    public String getRasterizerName()
    {
       return "NormalVector";
    }
    protected void renderLine()
    {
       int cdx = Math.abs( xR - xL);
      if (cdx==0)
          return;
       int i=0,k=0,xi=0;
       idx3d_Vector Np=Na,Ng;
       idx3d_Vector dN,Ni;
       Ng=Ret[k]. GetVector();
       dN= idx3d_Vector.sub(Ng,Np);
```

```
dN.x*=n_2/cdx;
dN.y*=n_2/cdx;
dN.z*=n_2/cdx;
for (int x=xL; x<xR; x++)
{
 if(count_n>2)
  if(Ret[k]. GetX()<xi )
  {
   Np=Ret[k]. GetVector();
   Ng=Ret[k+1]. GetVector();
   i=0;
   k++;
   dN= idx3d_Vector.sub(Ng,Np);
   dN.x*=n_2/cdx;
   dN.y*=n_2/cdx;
   dN.z*=n_2/cdx;
  }
   dN.x*=i;
   dN.y*=i;
   dN.x*=i;
  Ni=idx3d_Vector.add(Np,dN);
  i++;
  xi++;
  pos=x+offset;
  if (z<zBuffer[pos])
          {
           idx3d_Vector cv=Ni;
          float angle =
idx3d_Vector.angle(scene.light[0].v, cv);
          if (angle < 0) angle = 0;
          c = idx3d_Color.scale(color, (int)(angle*255));
          angle = idx3d_Vector.angle(h, cv);
          if (angle < 0) angle = 0;
          angle = (float)Math.pow(angle, n);
          int c2 = idx3d_Color.scale(0xFFFFFF,
(int)(angle*255));
          c = idx3d_Color.add(c, c2);
          screen.p[pos]=0xFF000000|c;
          zBuffer[pos]=z;
          if (useIdBuffer) idBuffer[pos]=currentId;
         }
         z+=dz;
         nx+=dnx;
         ny+=dny;
       }
   }
   protected void beforeRenderTriangle()
   {
   }
}
```

LISTING OF THE GouraudRasterizer4 module.java

```
public class GouraudRasterizer4 extends idx3d_Rasterizer
{
   private idx3d_Vector h;
   int i1, i2, i3;
   float ii12r, ii12g, ii12b;
   float ii13r, ii13g, ii13b;
   float ii23r, ii23g, ii23b;
   float liir, liig, liib;
   float riir, riig, riib;
   float lir, lig, lib;
   float rir, rig, rib;
   float i4r, i4g, i4b;
   double Pr[];
   double Pg[];
   double Pb[];
   private idx3d_Vector vA, vB, vC,nA, nB, nC ;
   double X1,X2,X3;
   double Y1,Y2,Y3;
   double X12,X23,X13;
   double Y12,Y23,Y13;
   public GouraudRasterizer4()
   {
   }
   protected void initRender()
   {
      h = idx3d_Vector.add(scene.light[0].v, scene.defaultCamera.lookat);
      vA = new idx3d_Vector(p1.n2);
      vB = new idx3d_Vector(p2.n2);
      vC = new idx3d_Vector(p3.n2);
      double cos_1 = idx3d_Vector.angle(vA, h);//  cos(Na H)
      double cos_2 = idx3d_Vector.angle(vB, h);//  cos(Nb H)
      double cos_3 = idx3d_Vector.angle(vC, h);//  cos(Nc H)
      double cos_4 = idx3d_Vector.angle(vA, vB);//  cos(Na Nb)
      double cos_5 = idx3d_Vector.angle(vA, vC);//  cos(Na Nc)
      double cos_6 = idx3d_Vector.angle(vC, vB);//  cos(Nc Nb)
      double t1=(cos_1*cos_4 - cos_2)/((cos_4 - 1)*(cos_2 + cos_1)) ;
      double t2=(cos_1*cos_5 - cos_3)/((cos_5 - 1)*(cos_3 + cos_1)) ;
      double t3=(cos_2*cos_6 - cos_3)/((cos_6 - 1)*(cos_3 + cos_2)) ;
      X1=Math.abs(p1.x+t1*(p2.x-p1.x));
      X2=Math.abs(p1.x+t2*(p3.x-p1.x));
      X3=Math.abs(p2.x+t3*(p3.x-p2.x));
      Y1=Math.abs(p1.y+t1*(p2.y-p1.y));
      Y2=Math.abs(p1.y+t2*(p3.y-p1.y));
      Y3=Math.abs(p2.y+t3*(p3.y-p2.y));
       ////////////////////////////
       int   v1 = calcColor(p1.n2);
       int   v2 = calcColor(p2.n2);
       int   v3 = calcColor(p3.n2);
       ////////////////////////////
      double Fr[][]={{0,0,0,0,0,1,idx3d_Color.getRed(v1)},
                {X2*X2,X2*Y2,Y2*Y2,X2,Y2,1,idx3d_Color.getRed(v2)},
        {X2*X2/4,X2*Y2/4,Y2*Y2/4,X2/2,Y2/2,1,(idx3d_Color.getRed(v1)+idx3d_Color.getRed(v2))/2},{X3*X3,X3*Y3,
        Y3*Y3,X3,Y3,1,idx3d_Color.getRed(v3)},X3*X3/4,X3*Y3/4,Y3*Y3/4,X3/2,Y3/2,1,
        (idx3d_Color.getRed(v1)+idx3d_Color.getRed(v3))/2},{(X2+X3)*(X2+X3)/4,(X2+X3)*(Y2+Y3)/4,(Y2+Y3)*(Y2+
        Y3)/4,(X2+X3)/2,(Y2+Y3)/2,1,(idx3d_Color.getRed(v2)+idx3d_Color.getRed(v3))/2}
      };
      Kramer sist= new Kramer();
      Pr=new double[6];
      Pr= sist. GetKramer(Fr,6,7);
```

```
    double Fg[][]={{0,0,0,0,0,1,idx3d_Color.getGreen(v1)},
                {X2*X2,X2*Y2,Y2*Y2,X2,Y2,1,idx3d_Color.getGreen(v2)},
      {X2*X2/4,X2*Y2/4,Y2*Y2/4,X2/2,Y2/2,1,(idx3d_Color.getGreen(v1)+idx3d_Color.getGreen(v2))/2},{X3*X3,X3*
      Y3,Y3*Y3,X3,Y3,1,idx3d_Color.getGreen(v3)},                {X3*X3/4,X3*Y3/4,Y3*Y3/4,X3/2,Y3/2,1,
      (idx3d_Color.getGreen(v1)+idx3d_Color.getGreen(v3))/2},
      {(X2+X3)*(X2+X3)/4,(X2+X3)*(Y2+Y3)/4,(Y2+Y3)*(Y2+Y3)/4,(X2+X3)/2,(Y2+Y3)/2,1,(idx3d_Color.getGreen(
      v2)+idx3d_Color.getGreen(v3))/2}
    };
    Pg=new double[6];
    Pg= sist. GetKramer(Fg,6,7);
    double Fb[][]={{0,0,0,0,0,1,idx3d_Color.getBlue(v1)},
                {X2*X2,X2*Y2,Y2*Y2,X2,Y2,1,idx3d_Color.getBlue(v2)},
      {X2*X2/4,X2*Y2/4,Y2*Y2/4,X2/2,Y2/2,1,(idx3d_Color.getBlue(v1)+idx3d_Color.getBlue(v2))/2},
                {X3*X3,X3*Y3,Y3*Y3,X3,Y3,1,idx3d_Color.getBlue(v3)},
{X3*X3/4,X3*Y3/4,Y3*Y3/4,X3/2,Y3/2,1,(idx3d_Color.getBlue(v1)+idx3d_Color.getBlue(v3))/2},
      {(X2+X3)*(X2+X3)/4,(X2+X3)*(Y2+Y3)/4,(Y2+Y3)*(Y2+Y3)/4,(X2+X3)/2,(Y2+Y3)/2,1,(idx3d_Color.getBlue(v
      2)+idx3d_Color.getBlue(v3))/2}
    };
    Pb=new double[6];
    Pb= sist. GetKramer(Fb,6,7);
  protected void prerenderFirstPart()
  {
  }
  protected void prerenderSecondPart()
  {
  }
  protected void prerenderLine()
  {
    renderLine();
  }
  public String getRasterizerName()
  {
    return " --------- ";
  }
  protected void renderLine()
  {
    int cdx = xR - xL;
    if (cdx == 0) return;
    for (x=xL;x<xR;x++)
    {

      double Ixyr=Pr[5]*x*x+Pr[4]*x*y+Pr[3]*y*y+Pr[2]*x+Pr[1]*y+Pr[0];
      double Ixyg=Pg[5]*x*x+Pg[4]*x*y+Pg[3]*y*y+Pg[2]*x+Pg[1]*x+Pg[0];
      double Ixyb=Pb[5]*x*x+Pb[4]*x*y+Pb[3]*y*y+Pb[2]*x+Pb[1]*y+Pb[0];

     float   cir = (float)Ixyr;
     float   cig = (float)Ixyg;
     float   cib = (float)Ixyb;

      if(cir<0){ cir=0;}
      if(cig<0){ cig=0;}
      if(cib<0){ cib=0;}
      pos=x+offset;
      if (z<zBuffer[pos])
      {
        screen.p[pos]=0xFF000000 | idx3d_Color.getColor(Math.round(cir > 255 ? 255 : cir), Math.round(cig > 255 ?
      255 : cig), Math.round(cib > 255 ? 255: cib));
        zBuffer[pos]=z;
        if (useIdBuffer) idBuffer[pos]=currentId;
```

```
            }
        }
    }
    private int calcColor(idx3d_Vector vector)
    {
        float angle = idx3d_Vector.angle(scene.light[0].v, vector);
        if (angle < 0) angle = 0;
        int c = idx3d_Color.scale(color, (int)(angle*255));
        angle = idx3d_Vector.angle(h, vector);
        if (angle < 0) angle = 0;
        angle = (float)Math.pow(angle, n);
        int c2 = idx3d_Color.scale(0xFFFFFF, (int)(angle*255));
        c = idx3d_Color.add(c, c2);
        return c;
    }
    protected void beforeRenderTriangle()
    {
    }
}
```

AN INTELLIGENT PLATFORM FOR CONDUCTING ECOLOGICAL SURVEYS OF WATER BODIES

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Abstract. *The article considers the relevance of using a new intelligent robotic platform to quickly conduct basic research on water quality assessment in reservoirs and analyze the relief of the reservoir bottom, preserving all the data. The paper proves that using an intelligent platform for water analysis significantly facilitates the research. Moreover, it increases the studied area of the reservoir. It simplifies the process of establishing the correspondence of data to a particular place on the reservoir compared to classical methods of water quality analysis in the reservoir.*

The presented technique allows to carry out studies of various types of pollution: radiation, heat, acid, industrial, domestic, organic, as well as to monitor the ingress of harmful substances into water bodies as a result of man-made disasters or the conduct of military operations.

It describes the platform's advanced design, which consists of a housing, a control board, sensors, actuators such as servo motors and a brushless motor, a radio module, a GPS module, and a motor speed controller. In addition, it illustrates the cutting-edge platform control panel. The article analyzes a functional diagram of an intelligent robotic platform for water quality assessment and bottom topography. It presents the study of the developed system carried out on the reservoir, the main idea of which was to study the correctness of the system's operation, evaluate the effectiveness of the conducted studies, and display water quality sensors. The paper studies an ultrasonic sensor for measuring depth and sensors for water acidity and temperature. It presents the outcomes of the developed monitoring system experiments that resulted in a map of the reservoir's bottom area and certain conclusions on water quality.

Keywords: *robotics, water quality, pollution, bottom map, ecology, geodesy, measurement, acidity.*

1. INTRODUCTION

Modern realities signify a rapid increase in consumption and the amount of waste. Therefore the question arises whether new digital technologies can compensate for these changes. The answer is obvious: it is necessary to look for new solutions that will help solve the problem of climate change and contribute to preserving the well-being of the entire planet.

Water pollution is the negative change in the physical, chemical, and bacteriological water properties caused by an excess of inorganic substances (solid, liquid, gaseous), organic, radioactive, or heat, which limit or prevent the use of water resources for drinking and economic purposes.

Natural reservoirs, such as oceans, rivers, and lakes, can self-purify. However, getting too many pollutants into their system can cause irreversible damage. Therefore, it all depends on the number of pollutants.

Too many chemicals, bacteria, and other microorganisms cause severe water pollution. Chemical, organic, and mineral substances form colloidal solutions and suspensions. Natural factors determine the chemical composition of pollutants, for example, the decomposition of substances in soil and rocks, the development and death of aquatic organisms, and anthropogenic factors.

Also, as a result of waging war, large-scale pollution of the environment occurs, which has catastrophic consequences for both people and nature.

There are no rules and restrictions in war, which can cause a lot of damage to humanity and the environment, trigger irreversible dangerous processes in nature and harm the entire planet. Pollution of various types causes deterioration of the chemical composition of soil, air and water. Various decay products can enter the water: radioactive substances, which cause the destruction of cells of living organisms; living organisms, which also causes significant pollution of water bodies and can have catastrophic consequences.

It is not excluded that explosive objects may enter rivers or lakes, which at any moment can cause a destructive effect even in times of peace.

Consequently, a robotic platform enables remote analysis of water in the reservoir to measure the acidity of water, its temperature, and the depth of the reservoir. In case of acidity increase and water pollution detection, it will be possible to take a water sample from a particular reservoir area and carry out a detailed water analysis in the ground laboratory. Moreover, the floating platform takes real-time readings from sensors and follows the executive mechanisms. Thus, it detects the source of pollution and marks the exact location by dropping a beacon in the highest pollution concentration for further.

Also, this platform can be used in the post-war period to analyze the quality of water bodies in order to detect an increased level of sulfur in them, as one of the components of gunpowder, and their subsequent restoration.

2. ANALYTICKI REVIEV OF THE LITERATURE

The problem of water pollution is becoming more significant. Water samples are usually taken in a reservoir in a certain area, with all the necessary data recorded. Further, these samples are sent to a specialized laboratory for a detailed analysis of the qualitative composition of the water. This process is time-consuming, but gives qualitatively accurate results. Some "mobile" laboratories allow conducting research in field conditions. However, it is also a long-term process that requires detailed preparation and preliminary water sampling.

There are no absolute analogs of the system presented.

The paper reviews the automated surface platforms that are fully autonomous or controlled in [1-5]. Therefore, they are suitable for extreme conditions to research in the ocean or transport cargo along a specific, established route.

In [6], the authors highlight an autonomous self-piloting system, which allows remote control of the vessel, receives information from sensors on the user interface, and has a complete picture of the vessel's state.

[7] suggested a spectral processing method for analyzing the reflectivity of water samples and applied machine learning methods to estimate water quality parameters.

Therefore, the investigation aims to develop an intelligent robotic platform for conducting geodetic and environmental research, which will be easy to manage, "mobile," and fast compared to similar systems. Moreover, it will also allow us to quickly make sets of water samples for more accurate and detailed analysis in the laboratory. In addition, it contributes to an actual experiment to assess the robotic platform's effectiveness and the system's correctness.

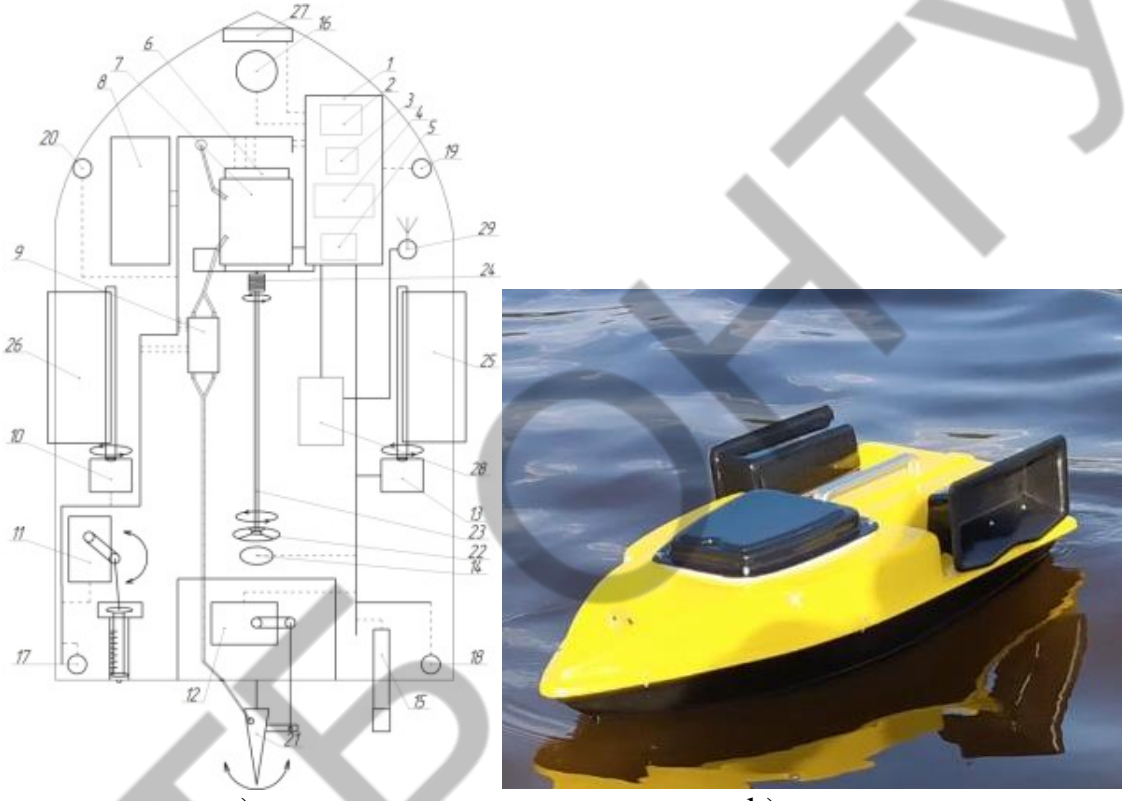
3. OBJECT, SUBJECT AND METHODS OF RESEARCH

3.1. The structure of the intelligent robotic platform

The design of the robotic platform (Fig. 1, a) consists of the following main elements: body; control unit (1), which includes a microcontroller based on an Arduino Nano board (2), a radio module (3), a JSNSR04T-2.0 sensor control board (4), a PH-4502C module to which a water acidity sensor is connected (5); collectorless engine (6), its cooling jacket (7), engine regulator (9) connecting clutch (24) for transferring rotation from the engine shaft to the deadwood shaft (23), which in turn is connected to the propeller (22)); the system is powered by a battery (8); servomotors (10), (11), (12) and (13) are used as cargo compartment drives (25) and (26), steering wheel drive (21) and water intake mechanism drive; sensors for temperature (14), acidity level (15), ultrasonic for measuring the distance from the bottom of the platform to the bottom of the reservoir (16), distance sensor (27); navigation of the platform is provided by the GPS module (28) and the antenna (29); overall emitters (17) – (20) help in driving in the dark. The appearance of the intelligent robotic platform for carrying out geodetic and environmental studies is presented in Fig. 1, b.

The platform equipment is powered by a Turnigy Li-Po 7.4V 5300mAh 2S2P 25C battery, which allows you to use the robotic intelligent platform for a long time and provides the necessary power supply voltage for the correct operation of the system. An Arduino Nano board built on an ATmega328 microcontroller was chosen as the control device. It is compact and enables all the tasks set in this project. For remote data transmission and platform control, the NRF 24L01P+ radio module is used, ensuring good signal reception and transmission quality at a distance of up to 1 kilometer. Furthermore, the following sensors receive data about the environment: ultrasonic distance sensor JSN-SR04T-2.0, which provides measurement of the distance from the swimming platform to the bottom of the reservoir and thereby allows displaying a map of the topography of the bottom by constructing a graph based on the data received from the sensor, as well as measuring depth in a specific place of the reservoir and make a preliminary calculation of the water volume of the reservoir; the DFRobot ADC151 water acidity sensor is used to analyse water quality, which helps to explore and determine the acidity of water almost

instantly; to measure the water temperature, a DS18B20 digital sensor is used with the function of an alarm signal for monitoring the temperature and the range of the measured temperature from 55 to +125 °C; the Sharp GP2Y0A21YK0F infrared distance sensor was used to determine floating obstacles that may appear in the path of the platform; to determine the exact location of this system and further build a map of the bottom and link the received data to exact coordinates, the GPS module GPS NEO-6M SMA + IPEX and the active antenna ANT GPS BY-GPS-07 SMAM were used to increase sensitivity and increase the ratio “signal-to-noise” and reducing the impact of interference.



a) b)

Fig. 1. Structural elements of the robotic intelligent platform (a) the robotic platform (b)

The executive mechanisms are in the form of MG995 Tower Pro and MG996R-180 servomotors, which are necessary to implement the water collection mechanism for its further in-depth analysis, as well as to ensure the movement of the swimming platform in the required direction and to unload the cargo placed in two cargo compartments on top of the platform.

3.2 Control panel

The control panel for this platform was also developed by modernizing the existing panel, the structural diagram of which is presented below.

Control is carried out by the Arduino Nano board, which provides data processing. Moreover, it performs the control device function and ensures data processing from the GPS module and their recording on a flash drive.

Sticks are employed to control the platform remotely; buttons are used to drive the cargo compartments and activate the water sampling system. LEDs are used to display the status of the system.

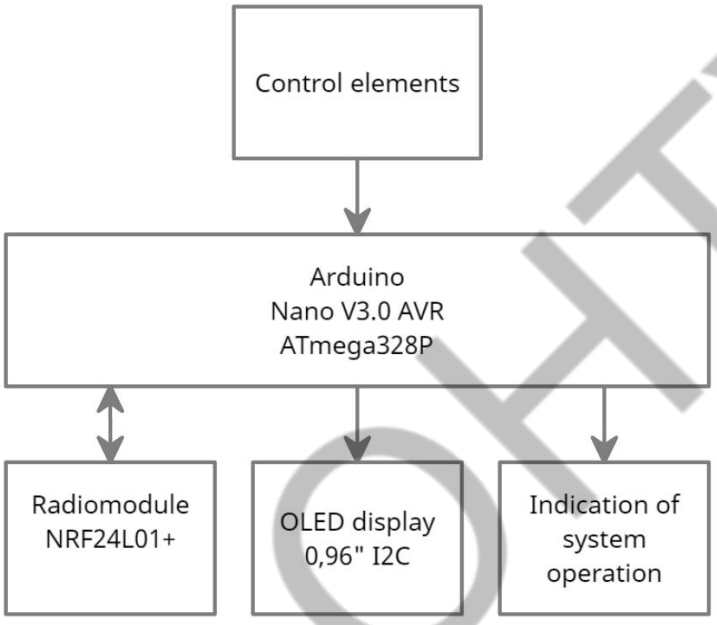


Fig. 2. Structural diagram of the remote control panel

The control panel receives and transmits data via the NRF 24L01+ radio module. The received sensor data from the radio module are processed by the control board and displayed on the OLED display of the control panel.

3.3 Algorithms of system operation

For the operation of the robotic intelligent platform, it is necessary to organize the synchronous operation of the swimming platform and the remote control (data reception and transmission). First, according to the system's algorithm (Fig. 3), the controller ports are configured, and the input data is zeroed. In this case, the transmitter considers the robotic intelligent platform, i.e., the initiator of the data exchange. Then a request is sent to the air to connect to the control panel. If there is no response, a cyclical request to connect to the control panel is sent again. If there is a connection and a signal is received, a response occurs to work on exchanging data with the remote control and checking the necessity of continuing work. If the work is finished, the cycle ends. If the system continues, cyclical work with the remote control takes place until the work with the remote control is finished.

The control panel operations algorithm (Fig. 4) begins with initialization. Then, the remote control acts as a receiver. Therefore, there is a wait for a free request on the air to connect to the robotic intelligent platform. In the absence of active requests, there is a cyclic wait for a connection request. In the case of a connection and receiving a signal, it is essential to exchange data with the platform and check the need to continue work. If the work is finished, the cycle ends.

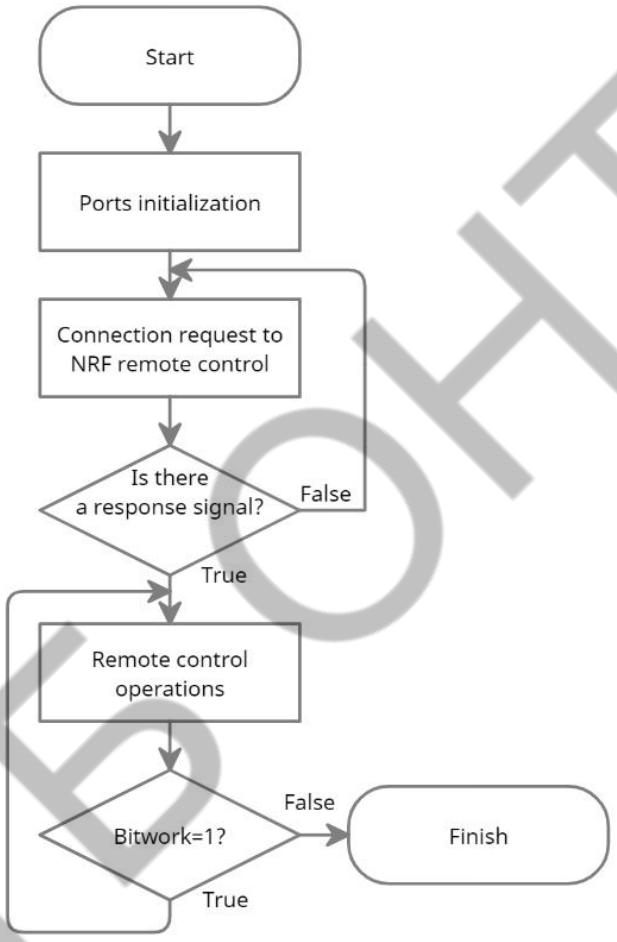


Fig. 3. The basic algorithm of the robotic intelligent platform

3.4 Features of the system

When activating the data recording system for building a three-dimensional model of the reservoir bottom, the system activation is checked, the GPS module and the SD module are launched, and their settings for operation are performed. The GPS module needs time to connect to satellites and determine its coordinates. Therefore, determining the coordinates of the robotic platform location takes time. Then a file is created to make further recordings of the depth sensor data and the corresponding coordinates. In addition, a timer is started, which is set to 10 minutes by default. During this time, the data will be recorded in the created file. Next, the coordinates and depth are cyclically read. Finally,

this data is written to a file with an interval of 30 seconds during the time set by the timer. This data file is the basis for constructing a wavelet diagram of the reservoir bottom section.

If the data recording system is activated again, it is checked whether the coordinates of the module are determined, and the work continues in the cycle. Otherwise, the reactivation of the system is expected.

With the help of radio modules, such data as control signals from the remote control are transmitted. They are responsible for the movement of the platform, turning on/off the dimensions, and collecting a water sample for deeper analysis. In addition, there is a data transfer received from sensors, namely water acidity level, temperature, depth, coordinates of the platform location, and battery charge level.

To create a map of the bottom relief, first of all, it is necessary to collect data on the depth of the reservoir using an ultrasonic distance sensor JSN-SR04T - 2.0. Then, two more parameters are needed to build a three-dimensional model. One of them is time, and the other is coordinates, the determination of which is performed using GPS data of the mobile platform location on the reservoir. Finally, when conducting research, it is necessary to choose a site on the reservoir and, moving through the reservoir step by step, receive data from the depth sensor and coordinates at these points, respectively, and write this data to a file on the platform of the RPi 3B+ mini computer installed on the mobile platform.

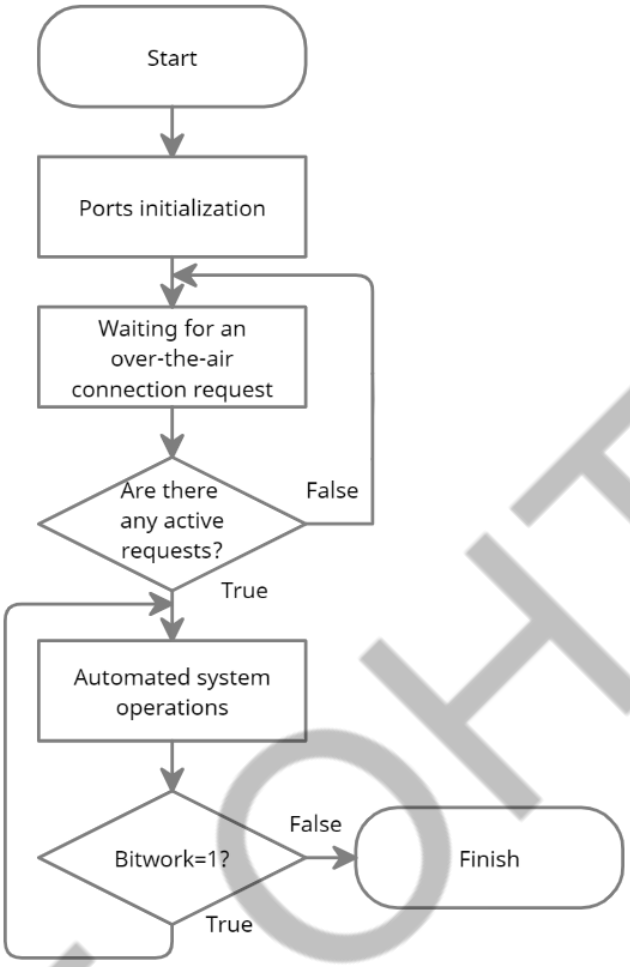


Fig. 4. Basic algorithms of the control panel

3.5 Data processing

The MATLAB system was used to process the data and build a three-dimensional relief model of the bottom of the reservoir, namely the Wavelet Toolbox, which provides functions and applications for analyzing and synthesizing signals and images. The toolbox includes algorithms for continuous wavelet analysis, wavelet coherence, synchrosqueezing, and dataadaptive time-frequency analysis. Using continuous wavelet analysis, it is possible to study how spectral functions evolve with time, identify common timevarying patterns in two signals, and perform timelocalized filtering. Discrete wavelet analysis helps to analyze signals and images in different extensions to detect discontinuities and other defects that are not easily visible in the raw data. In addition, it is possible to compare signal statistics on multiple scales and perform a fractal analysis of the data to reveal hidden patterns. Finally, with the Wavelet Toolbox, you can obtain a sparse representation of data valid for denoising or compressing data while preserving important features. Many toolbox functions support C/C++ code generation.

The investigation results prove that using wavelet transformations at the given stage of work is not entirely appropriate. Undoubtedly, it is necessary to follow a clear route to

use wavelet transformations. For instance, it is crucial to select the coordinates of a specific section, which are autonomously traversed robotically by the platform at the same speed, the same passes, and exclude measurement errors due to the influence of external factors.

4. WORK RESULTS

Before the experiment, the platform and all elements' efficiency were thoroughly checked. Then, a shallow water body was chosen for the test launch of the intelligent robotic platform and the necessary data collection. Finally, a route with different trajectories was traversed, and sensor data were recorded, which was the primary aim of the research.

All the research data is recorded in a file stored on a flash drive. It is convenient for further processing and analysis. Some recorded data is shown in Fig. 5.

A1 fx 9:42:34

A	B	C	D	E	F	G
9:42:34	50.236396	28.611356	155	24	6	5
9:42:37	50.236400	28.611360	146	24	6	5
9:42:40	50.236412	28.611358	140	30	6	4
9:42:43	50.236412	28.611354	134	29	6	4
9:42:46	50.236415	28.611351	145	29	6	4
9:42:49	50.236412	28.611351	132	30	6	4
9:42:52	50.236396	28.611356	144	30	6	4
9:42:55	50.236385	28.611362	144	30	6	4
9:42:58	50.236381	28.611370	135	30	6	4
9:43:01	50.236377	28.611373	151	30	6	4
9:43:04	50.236373	28.611377	136	30	6	4
9:43:07	50.236370	28.611379	147	30	6	4
9:43:10	50.236362	28.611383	156	29	6	4
9:43:13	50.236358	28.611383	131	29	6	4
9:43:16	50.236354	28.611383	138	29	6	4
9:43:19	50.236354	28.611381	147	29	6	4
9:43:22	50.236354	28.611377	149	29	6	4
9:43:25	50.236354	28.611375	99	29	6	4

Fig. 5. Recorded data from a flash drive

The GPS module determines the current location and indicates the exact time regarding the location in specific coordinates. The data analysis makes it possible to build a map of the intelligent robotic platform's route and a two-dimensional depth graph (Fig. 6).

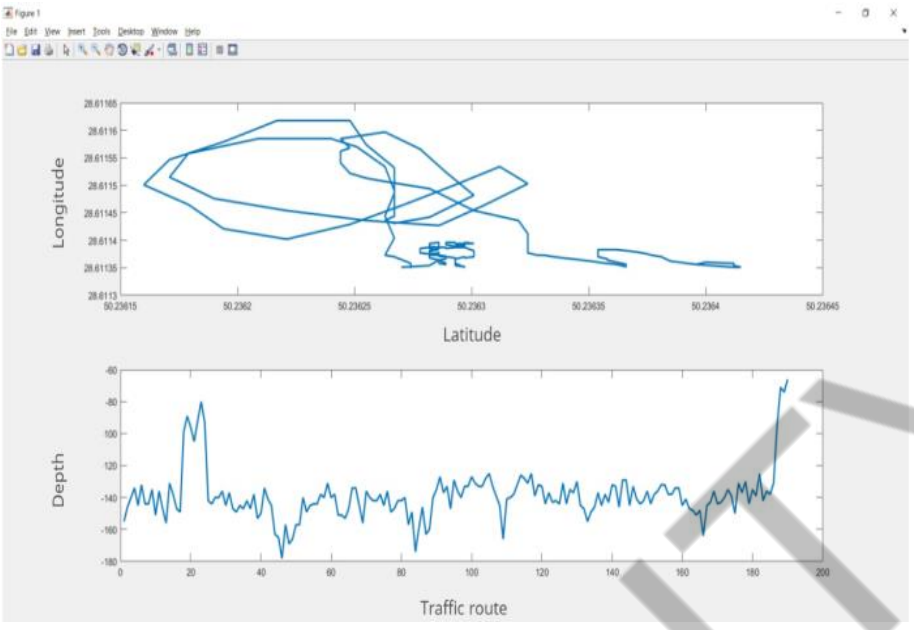


Fig. 6. Intelligent robotic platform movement route and two-dimensional depth plot

Furthermore, a three-dimensional model of the reservoir bottom was built based on the platform's route data and measured data at specific points along the route. However, it is not highly detailed, as it considers only the specified points of the route. Thus, to increase its informativity, all intermediate points must be filled with relevant data (Fig. 7.).

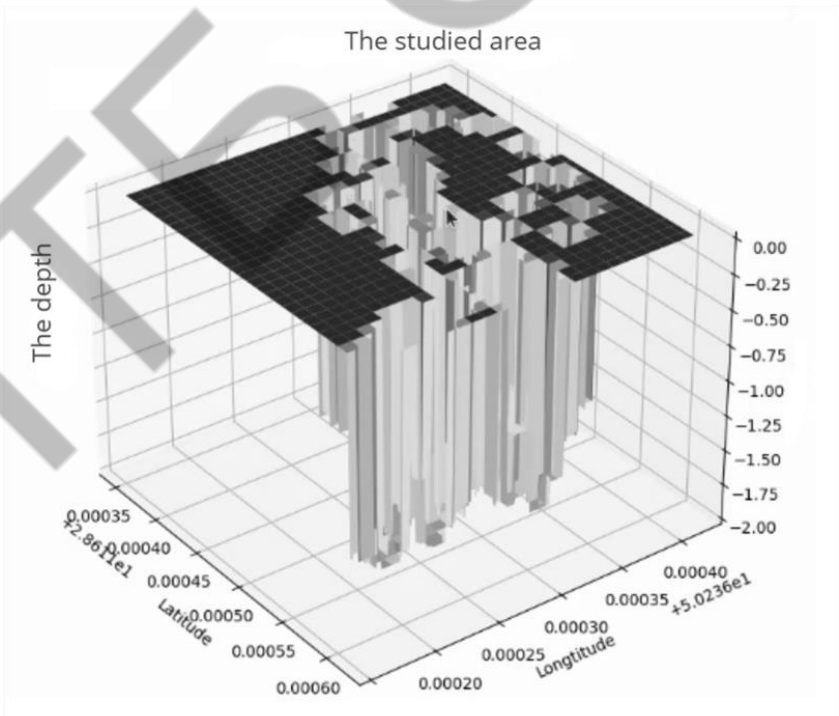


Fig. 7. Three-dimensional model of the bottom of the reservoir

According to the readings of the temperature and acidity sensor at each determined point of the robotic platform route, graphs of changes in these values were built (Fig. 8, 9).

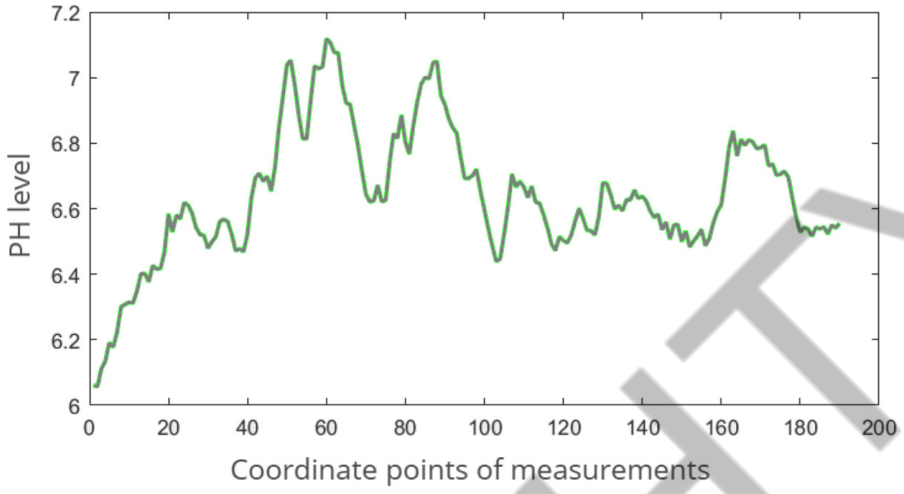


Fig. 8. Changes in water acidity in the reservoir

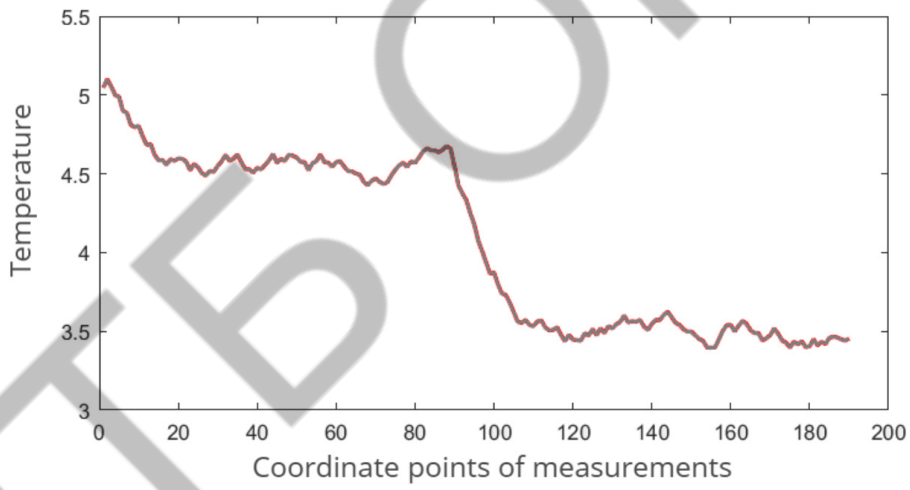


Fig. 9. Water temperature changes in the reservoir

5. CONCLUSIONS

The research introduces a new intelligent robotic platform for geodetic and ecological studies of water bodies. It helps assess water quality and measure a water body's depth. It provides a detailed layout of all structural elements, describes the methodology, and clarifies further data processing. Sensitive system elements such as temperature, water acidity, and distance sensor were chosen, which meet all platform installation requirements. Finally, it investigates the effectiveness and correctness of the system performance on a natural reservoir (a river and a lake). Furthermore, all necessary measurements were taken, including a water sample. Based on the results, conclusions

were made about the water quality in the reservoir. Moreover, three-dimensional models of the studied bottom area and graphs of changes in the values (temperature and acidity) were constructed. In addition, the research highlights the problem of using a wavelet diagram to describe the area of the reservoir bottom.

The installation has a set of functions, which can be increased in the future, for example, adding the function of work autonomy at specified points, which contributes to building a full-fledged detailed map of the reservoir bottom. In addition, the article considers the possibility of a more detailed analysis of water locally.

It is also possible to equip the structure with various types of sensors that will be able to do not only a chemical analysis of water quality, but also be able to detect metal objects at the bottom of the reservoir with markings on the map for further research of such objects.

There are also plans to expand the functionality of this intelligent robotic platform by installing an intelligent gravimetric system on it, which will allow conducting geodetic and geophysical surveys of water bodies in order to identify the qualitative composition of the Earth's surface and possible accumulation of rocks of anomalous density directly at the study points.

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ORGANIZATION OF A BACK-UP CHANNEL OF COMMUNICATION IN A LOCATION WITH NO CELLULAR COMMUNICATION INFRASTRUCTURE

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Abstract. *In this work, we considered the organization of a backup communication channel with a remote point in emergency situations or in the absence of cellular communication. The maximum distance of information transmission was evaluated using several models of radio wave propagation. The battery life of the device is calculated. A prototype of the device has been developed.*

Keywords: *range of communication, LoRaWAN, Okumura-Hata, propagation of radio waves, communication in emergency conditions, rescue services.*

I. INTRODUCTION

The importance of information transmission as a provision of communication channels in the life of modern society is constantly growing. The development of communication technologies in the context of globalization is of primary importance and is taking place at an undeniably fast pace, growing in geometric progression, but it is mainly commercialized for the mass consumer and is represented by CDMA and GSM communication (Fig. 1) [1].

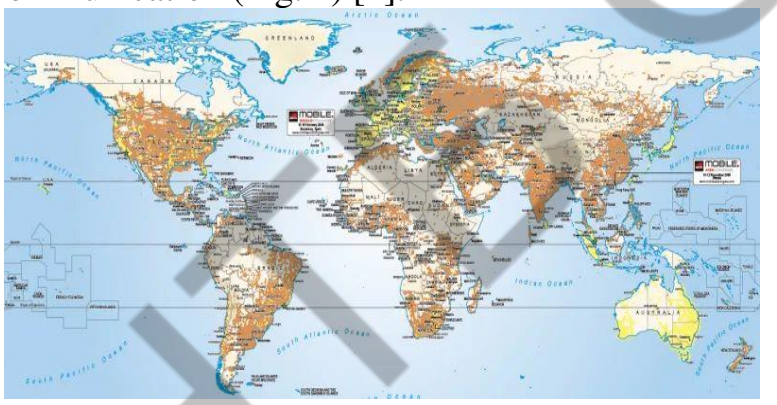

Fig. 1. Coverage of the Global System for Mobile Communications (GSM) in around the world for 2020.

If it is about identifying and saving human lives that are in danger due to force major circumstances - such as a plane crash, a shipwreck, derailment of a tourist group's route, conducting special intelligence operations in the fight against terror and reporting the necessary coordinates, then, unfortunately, the reality is this.

Lack of access to systems satellite and cellular communications due to obvious reasons in these circumstances or the possibility of its tracking (in conditions of rescue of hostages, for example) may cause human casualties. Therefore, it is objectively necessary to solve the problem of backup communication channels.

Even if devices for CDMA or GSM communication are available, there are still many areas on earth without coverage of these networks (Fig. 1.1). In the figure, we can see that even in highly developed countries, 100% is missing

coverage of territories with communication. There are still many areas in the world, especially in developing countries, where researchers, tourists, people who have suffered a ship or plane crash, and even the general public, may find themselves without communication, and therefore without help, in the event of force majeure.

Therefore, the development of backup communication channels is still relevant.

II. LITERATURE ANALYSIS

2.1 Existing backup communication systems for searching and rescuing people

At the end of the twentieth century, the COSPAS-SARSAT [2] people search system was developed. In emergency situations on ships and airplanes, a special device notifies about such a situation and the location of personal radio buoys installed on them. Any individual can purchase such a device for $350[3].

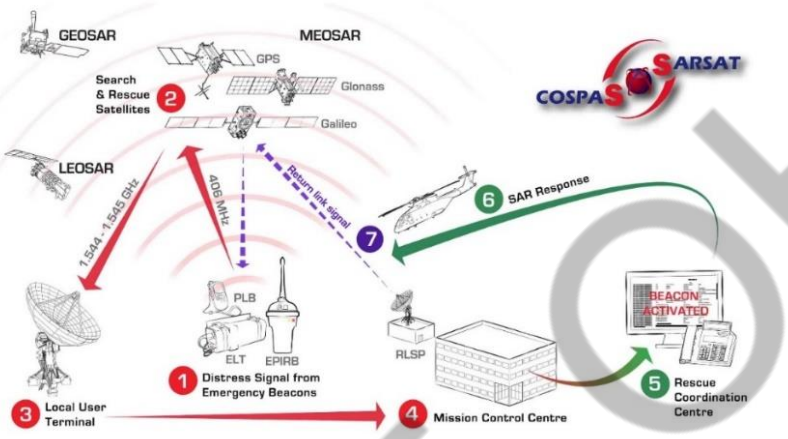

Fig. 2. Principle of system operation COSPAS-SARSAT

The principle of operation of the COSPAS-SARSAT system is that the coordinates of a place in this system are determined not on the ship by satellite signals, but at the shore station (information reception point) by the signals of a radio buoy relayed via a satellite. But even such a convenient rescue system has several drawbacks.

Not all countries have joined this alliance. The delay time for the delivery of information can reach up to 1.5 hours in the northern hemisphere and up to 2 hours in the southern hemisphere. There is also no feedback. The error of the system is about 20 km (if no GPS receiver is used), which is quite a lot. The presence of the listed shortcomings forces us to search for new directions for solving the problem of backup communication in an emergency situation for areas with no cellular infrastructure.

2.2 Alternative backup communication systems

To date, there are many systems for organizing communication in hard-to-reach places, all of them are quite different, starting from the fundamental difference and the necessary operating conditions and, of course, the cost of building and using such a system. One of the widely used such systems are radio stations, they enable the transmission of speech information in encrypted or open form over short, medium and sometimes quite long distances, depending on the class.

The most popular technologies used for backup communication can be classified as follows:

1) HF radio station
2) VHF radio station
3) Satellite communication

HF radio stations are transceivers operating at frequencies from 3 to 30 MHz. CV is divided into two subtypes. The first is a range that uses 3 - 25 MHz, which allows you to organize communication over long distances (transcontinental). And the second 25.6–30 MHz "Civilian" range is "Ci-B". The only range in which radio communication equipment can be used by private individuals without restrictions. The high range of communication in flat rural areas and the low cost of subscriber equipment make this range very attractive for various categories of users, from farmers, fishermen and shepherds to large construction, mining and transport organizations. Among the advantages, we can say the low cost of the equipment and the simplified registration procedure, which can be used by ordinary people.

VHF radio stations are stations for two-way transmission of ultra-short radio waves on ships, cars and ships to ensure the safety of work and movement. Unlike HF radio stations, portable VHF radio stations are smaller in size and weight than HF radios, have better autonomy, have a maximum range of about 10 km in open terrain, and a moderate price. The most popular brands of such radio stations are Icom, AOR, Kenwood, Motorola, etc.

Satellite communication is represented by the most common companies Iridium [4], Thuraya[5], Starlink[6] they have advantages - a very large coverage area, but some of them have a large mass (inStarlinkthe terminal weighs 8.5 kg) and volume, often the high price of the device and subscription (subscription fee), not much autonomy around the clock.

The problem of organizing backup communication at a distance of more than 10 km with affordable and compact terminals with high autonomy remains relevant. Longer range communication usually requires a fairly tall transmitter antenna to compensate for the curvature of the Earth and thus provide a line of sight. This is the main idea in this scientific work.

2.3 LoRaWAN trackers

LoRa is a new, spread-spectrum modulation method that allows low-speed data to be sent over long distances with minimal power consumption. LoRaWAN (Long Range wide-area networks) is the most well-known hardware protocol with LoRa, which is designed to manage communication between LPWAN gateways and end devices. More importantly, there are no access fees with this type of wireless technology. Therefore, some researchers [7-9] decided to use LoRaWAN technology to create GPS trackers. The LoRaWAN GPS tracker (GPS-LoRaWAN) is a battery-powered tracking device that uses the GPS satellite positioning service to determine its location and transmits the received coordinates using LoRaWAN radio technology. The intervals between measurements can be freely adjusted to adapt the device to individual needs. The built-in motion sensor detects changes in the movement of the device (if it is picked up or transported in a vehicle). This allows the device to switch between an active mode, in which frequent

updates are downloaded during movement phases, and a sleep mode, which conserves battery power by sending only a few messages. Based on the specification [10] and the features of the LoRaWAN technology, we can conclude that it is quite a promising technology for the organization of backup communication in an emergency situation.

III. DEVELOPMENT OF BACKUP COMMUNICATION CHANNEL STRUCTURE BASED ON LORAWAN TECHNOLOGY

3.1 Object of research

The subject of research there is a set of theoretical and applied aspects of the mechanism organization of a backup communication channel with a remote point based on the LoRaWAN system.

User devices in LoRaWAN are divided into three classes:

– class A: after broadcasting, the device waits for a response from the BS, and then turns off the receiver until the next communication session;

– class B: the receiver of the device is turned on according to a predetermined schedule. The BS knows this schedule and therefore can transmit information to the device in accordance with it;

– class C: the receiver is always active, so the BS can transmit information at any time [11].

Strengths of LoRaWAN:

– due to minimal energy consumption for the transfer of small data packets, the energy consumption level of the end device is low;

– compared to other wireless technologies used for telemetry, radio signals travel long distances of 10-15 km in non-line-of-sight conditions and evidence of 766 km in line-of-sight conditions [12];

– in conditions of urban development, when using frequencies of the sub-gigahertz range, LoRaWAN has a high penetration of radio signals;

– no need to obtain frequency licenses and pay for the radio frequency spectrum due to the use of unlicensed frequencies;

– high scalability for large networks;

– relatively small cost.

Weaknesses of LoRaWAN:

– there are risks that the spectrum of the unlicensed frequency range may be noisy;

– the LoRa modulation technology is currently closely supported only by the patent of the Semtech company, which causes the impossibility of its application without this company;

– limiting the maximum signal power [13].

The network based on LoRaWAN consists of terminal devices (End-Device), gateways (Gateway), network servers (Network Server) and application servers (Application Server) (Fig. 3 a). The terminal device sends data to the gateway (Uplink), the gateway forwards it to the network server, and the network server forwards it to the application server as needed.

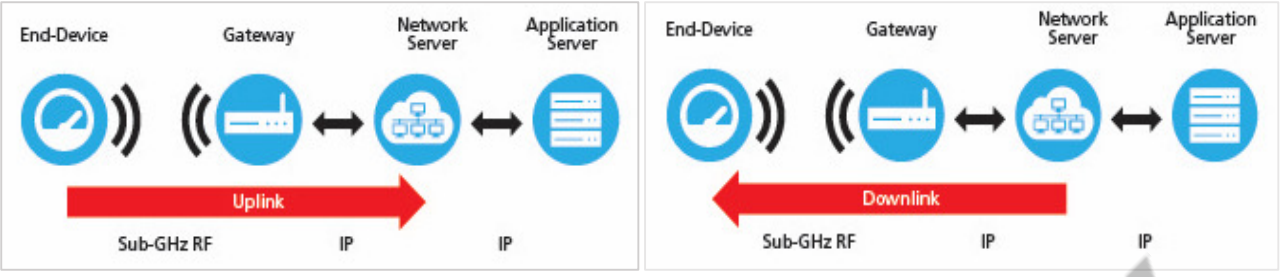

Fig. 3. LoRaWAN transmission: a - Uplink transmission, b - Downlink transmission

In addition, the network server can send messages (for network management or on behalf of the application server) to end devices through the gateway (Downlink) (Fig. 3. b).

Table 1 a contains summarized data for various parameters in the European frequency range.

Table 1. LoRaWAN specification

Parameter	Value
Frequency range, MHz	863-870
Maximum number of channels	35
UL radio signal spectrum width, kHz	125/250
DL radio signal spectrum width, kHz	125
Modulation	LORA, GFSK
Transmission power UL, dBm	2-14 20 (optional)
Transmission power DL, mW	1-25 100 (optional)
Transmission power DL, dBm	14
SF spectrum broadening factor	7-12

Consider the operational communication system, which is built on the basis of the LoRaWAN standard. Their main feature is a long range of communication with a rather small transmitter power, which determines the good autonomy of the device. Since the radio modules have very little power, there is no need for a radio amateur license and there is no need to register modems with national organizations responsible for spectrum managers.

The principle of maximum simplicity and cheapness of the solution is embedded in the concept. The structure of such a system should look as follows: client device of the sender; the LoRaWAN transmitter is equipped with a Bluetooth module for receiving information; base station (BS); recipient's client device.

Let's consider options for the development of events in which it is possible to use the communication system on based the LoRaWAN standard. Figure 4 simulates three situations of searching for a person or a group of people who are lost. They were previously issued with a LoRaWAN mobile transmitter.

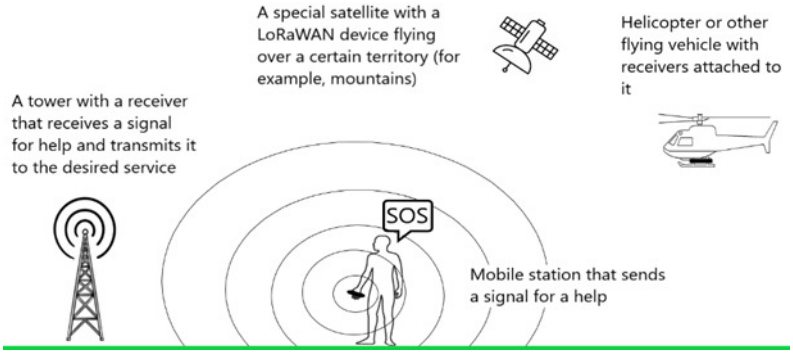

Fig. 4. Schematic view of the coverage organization for mobile transmitter communication

There are three ways to receive SOS signal, each type has its own advantages and disadvantages. The first is to locate ground base stations in a certain area (for example, in mountains or dense forests). The second is to send a helicopter or other aircraft over the likely location of those who are lost.

And the third is to use a satellite or a group of satellites that will constantly monitor the situation over a certain area. Each of these methods has its advantages and disadvantages.

To achieve a better result and a longer range of the alarm message transmission, the transmitter (or transmitter antenna) should be as high as possible relative to the Earth. Due to the light weight and compactness of the device, it can easily be thrown up using a special slingshot, which will be included with the device. An analogue of such a slingshot is usually used for fishing, it is capable of shooting at a distance of up to 400 meters [14], so it can easily raise the device to a height of about 30 meters to transmit information.

Also, to achieve a better result, due to the stability of the height, you can attach the device to quadcopter, and raise to the height necessary for direct visibility conditions. To select the moment at which information needs to be transmitted, the device will be equipped with an accelerometer to monitor the peak flight height of the transceiver in the air.

The typical transmission time of one message, depending on the channel settings, is from 0.1 to 2 s. Accordingly, the transfer speed is quite low - from approximately 100 Bit/s in the most long-range mode (far, but slow) to 20 kBit/s in overclocked mode (fast, but not far). Therefore, unfortunately, at such speeds there can be no transfer of media content, such as images or even more so video. The task of the developed system is simple - to send the shortest possible SMS message with the subscriber's coordinates and receive a response.

3.2 General description of the message transmission process

The system requires the equipment described in Fig. 5, as well as a client device for uploading information to the transmitter. It can act as a smartphone equipped with a Bluetooth module and on which special software is installed.

Message transmission process:

1. The sender is included in the application;
2. Connects to the device using Bluetooth;
3. Selects the required mode of operation (information transfer);
4. Enter a message in the text field;
5. After saving the message, the information is transmitted via Bluetooth to the LoRaWAN module;

6. The device rises into the air to the height required for direct visibility with the help of quadcopter, or on the most possible with the help of a slingshot;

7. In flight, the accelerometer measures the acceleration, and when it drops to a certain value, it transmits a signal to the LoRaWAN module;

8. The LoRaWAN module sends a message to the BS.

Points 1-5 need to be performed only in case of sending a random message. If it is enough to send a standard message, for example, "SOS, Full name (or pseudonym), my coordinates: 49.9808100° 36.2527200°", then for this you need to press a special button on the transceiver itself.

The base station works in reception mode and, after receiving a message, forwards it to the rescue service. A computer, laptop or tablet that has a direct local connection to the base station or to a cloud server via the Internet can act as a client device for the recipient of an alarm message.

3.3 General description of the process of receiving a message

Since most of the time the device is quite low and cannot immediately receive an arbitrary message from the base station, a mechanism is needed to send a delayed message. In order to send messages when the receiver is at a height sufficient for reception, it is necessary to develop an algorithm for the operation of the base station.

As a solution to the above problem, we offer the following synchronization algorithm:

1) The sender (on the BS side) selects the recipient and downloads the information;

2) Information is stored until the BS receives a signal from the device that it is ready to receive data;

3) In the mobile application, the user selects the "Receive message" operating mode;

4) The device rises into the air to the required height;

5) In flight, the accelerometer measures the acceleration, and when it drops to a certain value, it transmits a signal to the LoRaWAN module;

6) The LoRaWAN module sends a 1-bit message to the BS, which signals readiness for reception, and immediately switches to reception mode;

7) After receiving the BS signal, it automatically transmits the saved information after the shortest pre-arranged time;

8) The receiver connects the phone / tablet / laptop via Bluetooth to the device and receives the message.

It should be noted that the procedure described above is for receiving an arbitrary message from the base station (rescue service). To receive the standard message, for example, confirmation of message delivery, it is enough to watch the LED on the transceiver body.

That is, in most cases, the basic functionality of the system remains functional even without a working smartphone.

3.4 Development of the hardware part of the device

Figure 5 shows a functional diagram from which you can understand that we need the same components to build the final device: The LoRaWAN module is equipped with an antenna; The Bluetooth module is equipped with an antenna; The GPS module is equipped with an antenna; accelerometer; battery with a battery charge control module (if necessary). The LoRaWAN module has three main requirements: maximum compactness, the presence of a connector for connecting the battery, and support for the SF 12 parameter to ensure the maximum transmission range. All the above requirements are met by the RAK 3244 BastWAN card.

The communication board RAK 3244 BastWAN - for wireless switching of IoT devices weighs only 6.9 grams, and is built on the RAK4260(H) module.

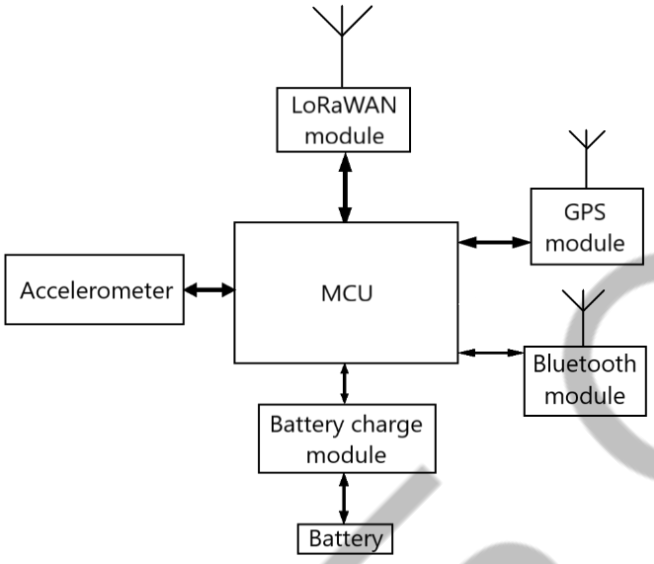

Fig. 5. Functional diagram of the device

The latter includes a Microchip SAML21 32-bit ATSAMR34J18 SiP processor consisting of several cores: ARM Cortex M0+ 48MHz and a LoRa SX127x transceiver. RAK3244 is compatible with the LoRaWAN 1.0.2 specification and supports Point-to-Point communication. LoRa low power consumption and broad communication capabilities make it suitable for many Internet of Things (IoT) applications, such as home automation, sensor and sensor networks, building automation, personal networking applications, and more.

GPS receiver - a radio receiver for determining the geographical coordinates of the current location of the receiver's antenna. GPS Click LEA-6S [15] is suitable for our purposes. Due to its small size, 3 modes of operation and low price. Bluetooth is a standard communication protocol that is primarily designed to be low power with a short range based on low-cost receiver microchips in each device. Since the devices use a radio communication system (broadcasting), they should not be in the direct line of sight of each other [16]. For the prototype of our device, let's stop at Bluetooth version 5.0 on the nRF52810 chip, which is installed on the HOLYIOT-21014 module and which we will consider next.

An accelerometer is a device that provides the ability to measure and analyse linear and angular acceleration. This device is needed with our device to track the peak point during the flight of the beacon and start sending a signal to ensure the maximum coverage area. You can also add an emergency tracking function so that if a person starts moving fast in a certain direction and brakes suddenly with overloads above a critical value, the accelerometer will detect it and activate the transmitter to send SOS signal.

The main requirements for the accelerometer module for the device are maximum energy efficiency, compactness and affordability. One of the possible options that satisfies all of them is the HOLYIOT-21014 module equipped with an LIS2DH12 accelerometer. HOLYIOT-21014 is also equipped with a Bluetooth 5.0 module built on the nRF52810 chip, and despite all this, the dimensions of the entire module are only 25 mm x 25 mm [17].

3.5 Device for increasing the height of the transmitting antenna of a mobile station

The next objective stage of consideration of our topic is the determination of the question of how the mobile station will be launched into the air and transmit information. To solve this problem, it is possible to use a quadcopter or a slingshot as a device for launching a mobile station. Below are the technical characteristics of some of them.

Table 2. Comparative characteristics of quadcopters and slingshots

	Quadcopter	**Slingshots**	
Model	DJI MAVIC 3	Slingshot with coil	SlingFish B
Maximum lifting weight	200 gr	200 gr	250 gr
Price	$4,814.62	$19.86	$20.40
Maximum range	32 km	300 m	250 m
Maximum flight time	45 minutes	-	-
Max. flight height	6000 m	-	-
Dimensions	347.5×283×107.7 mm	16.8x11.2 cm	15.8 11.4
Weight	900 gr	442 gr	215 gr

Let's consider the positive and negative aspects of using these devices in the conditions of a tourist trip or searching for missing people as a result of a plane crash, etc. For quadcopters, the "plus" is a long flight range; the possibility of aerial reconnaissance; and "cons": high cost; lack of possibility of urgent repair; considerable dimensions. When using a slingshot, the advantage is low cost, small dimensions and weight, components are easily replaced and inexpensive. And the disadvantages are the small flight range of the object relative to quadcopters. Based on these results, it can be concluded that in the specified conditions, the slingshot has many more advantages over the quadcopter due to its weight, price and volume.

3.6 Design of the alarm transceiver

After all the necessary components are selected, you can proceed to the housing in which the product will be located.

When designing, it is necessary to take into account the shape of the case, so that when it is launched from a slingshot, the product has minimal aerodynamic resistance and does not interfere with height gain. It should also be taken into account that after such a launch, all internal components must remain intact, that is, the case must be impact-resistant and withstand a fall from a height.

That is, the main requirements for the case are as follows: maximum impact resistance; minimum size; aerodynamic shape.

In addition, if you develop a mechanism for which the product will descend as smoothly as possible after being thrown up, it will provide additional time for the transmission of information and, at a lower speed of fall, will reduce the risk of damage to internal components.

To ensure an aerodynamic shape, we suggest using a cylindrical shape with a cone-shaped antenna. Such a form is able to provide predictability in the air at the moment of gaining altitude and at the moment of falling. It also makes it possible to place the components well inside, so the accelerometer + Bluetooth module can be placed at the base (bottom) of the cylinder, the LoRaWAN radio module and the battery in the middle, and the antenna of the radio module can be removed from the top of the cylinder. Since the antenna can be in the form of a spring (Fig. 6), it can take a shock when it falls on itself and provide cushioning. For additional cushioning, the inside of the antenna can be a soft foam material, such as that used in the soles of modern sneakers.

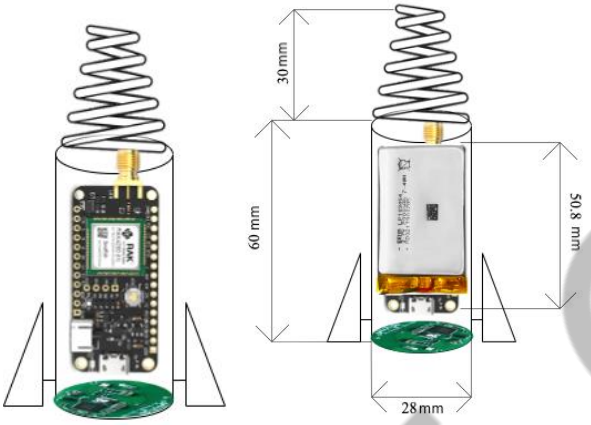

Fig. 6. Placement of components in the case

We offer a simple mechanism with wings that open when falling. At the moment when the product has reached its peak height and free fall begins, the accelerometer reports this, the latch releases the clamped spring, which opens 2 wings at an angle of 45°.

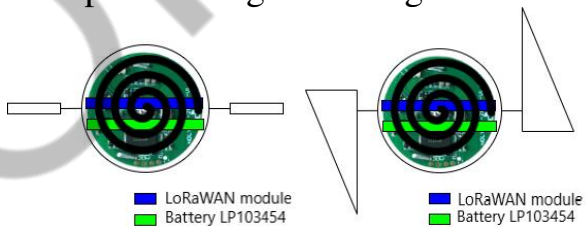

Fig. 7. Top view of the device with closed and open wings

Thanks to this design, the device will start to spin, which will reduce the speed of its fall. The spring is retracted by returning the wings to their initial position.

IV. RESULTS

4.1 Calculation of device autonomy

To choose the optimal power source (battery), it is necessary to calculate the energy consumption of the system and the desired autonomy. The autonomy calculation was performed according to the algorithm shown in Fig. 9.

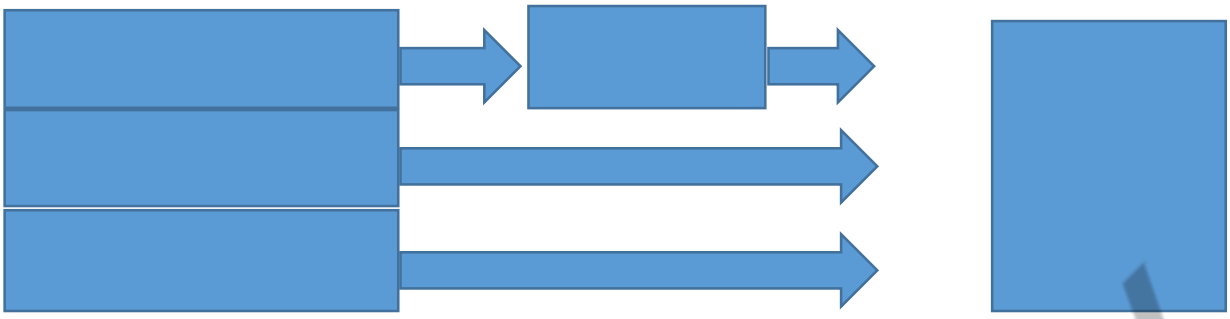

Fig. 9. Algorithm for calculating device autonomy

To perform calculations, you need to consider the energy consumption of all structural elements of our device for different modes (states). The data for the main components of the devices are given in Table 3.

Table 3. Energy consumption of the main structural elements of the device

Regime	**Microcontroller**	**GPS receiver**	**LoRaWAN modem**
Sleep	130 · 10-6	0.3 · 10-6	0.2 · 10-6
Measurement	230 · 10-6	1.5 · 10-6	0.2 · 10-6
Transfer	230 · 10-6	0.3 · 10-6	29 · 10-3
Acceptance	230 · 10-6	0.3 · 10-6	10.8 · 10-3

The results of calculating the autonomy of the device when powered by the LP103454 battery (2000mA) are shown in Fig. 10.

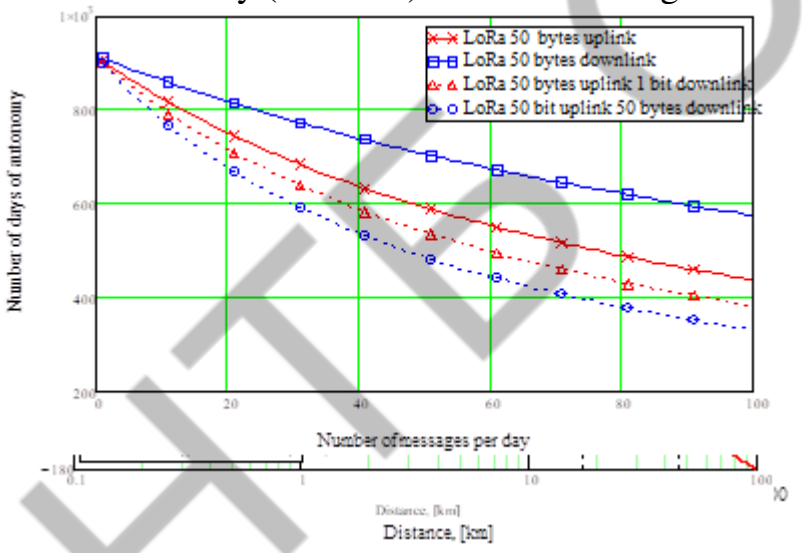

Fig. 10. – Dependence of the number of days of autonomy of the ZP on the number of messages per day

Analyzing this graph, we can say that when using a LiPo battery with a capacity of 2000mA, the autonomy of the device will reach approximately 330 days without recharging, under conditions of transmission and reception of 100 messages per day, each 50 bytes in size.

4.2 Assessment of the maximum range of information transmission

When designing a system that transmits information over a radio channel, the maximum distance between the transmitter and the receiver is one of the most important parameters that will have the greatest impact on the system design process. Selection of the correct communication range allows you to avoid increasing the output power, using

repeaters or amplifiers. When creating a radio communication system, you must always strive to ensure the maximum distance. If the communication range is too long, it makes sense to reduce the output power and, as a result, the current consumption.

Choosing the optimal system frequency in the ISM range (0.169...2.4 GHz) is not always obvious. Antenna characteristics and location, regulatory limits on maximum output power, unwanted sources of interference, operating frequency, radio configuration, and propagation attenuation all determine the maximum distance between receiver (Rx) and transmitter (Tx).

Since the information transmission technology has already been chosen, it is necessary to rely on its existing technical characteristics listed in table 3.1.

4.2.1 Conditions of direct visibility

To calculate the maximum, we will use the empirical formula of line of sight LoS[18]:

$$R = 4{,}12 \times \sqrt{(ha + hp)} \tag{4.1}$$

Where *ha*— lift height transmission antennas,

hp — elevation height of the receiving antenna.

In Table 4. assume several communication scenarios when the alarm signal transmitter is on the ground (for example, a person is unconscious), at a height of 1 m and 2 m (in equipment or in the hands of a person), 20 m (the transmitter is thrown up using a slingshot or a compact quadcopter) and for different heights of the receiving antenna (base station), for a ground base station (10m and 30m) and an aerial base station, such as a quadcopter or helicopter (100m and 5000m).

Table 4. The maximum range of information transmission in various conditions

ha/ hp	**10 m**	**30 m**	**100 m**	**5000 m**
0 m	13 km	22 km	41 km	291 km
1 m	13.66 km	22.93 km	41.4 km	291.35 km
2 m	14.2 km	23.30 km	41.6 km	291.38 km
20 m	22.56 km	29.13 km	45.13 km	291.91 km

To clarify the results, we will use the Fries model, which is used to determine the distance d of radio systems in an open environment and free space and can give estimated results for real systems with highly raised antennas:

$$\underset{Friis}{Pr} = Pt * \frac{G_t * G_r * \lambda^2}{(4\pi)^2 * d} \tag{4.2}$$

where: $\underset{Friis}{\Pr}$ - signal strength at the receiver input;

Pt - transmitter power;

G_t - the gain of the transmission antenna;

G_r - the gain of the receiving antenna;

λ –wavelength.

The optimal set of parameters of the LoRaWAN protocol is selected to calculate the power at the receiver input and subsequent comparison with the threshold sensitivity, which allows to calculate the range of the communication channel. One of these parameters is SF (spreading factor) - a coefficient to which transmission and reception parameters are tied. SF is a whole number, in the standard it is provided from 12 to 7. The higher the SF, the better the protection against interference in the radio channel and, accordingly, the greater the range, but the lower the speed and, accordingly, the longer the transmission takes on the air. According to the specification [19], the sensitivity of the LoRaWAN receiver, depending on the parameter SF, is in the range from -118 to -136 dBm.

The calculation results are shown in Fig. 11.

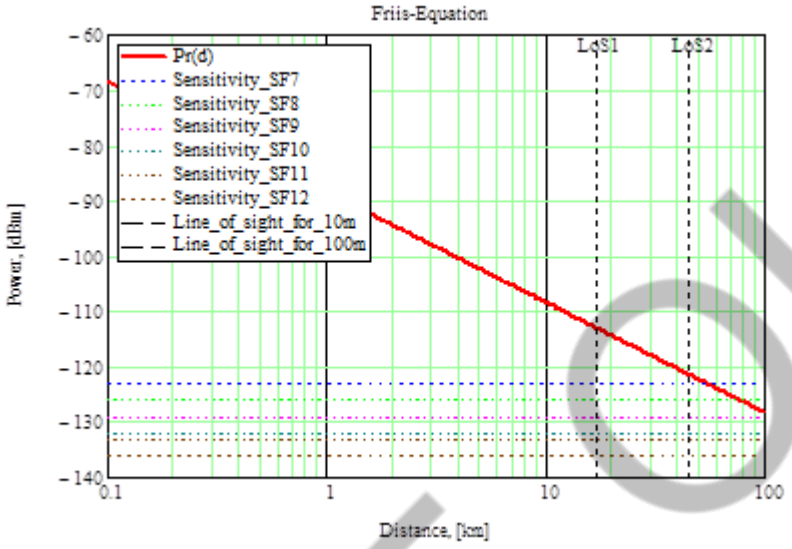

Fig. 11. Dependence of the LoRaWAN radio signal power at the receiver input on the distance to the transmitter (Fries model)

The maximum distance is about 120 km. The known record values for this time, obtained experimentally, are 741 km and 766 km, while the height of the transmitter was 33 km and 25 km, respectively [20]. In that experiment, LoRaWAN modules were launched on a balloon.

4.2.2 LoRaWAN radio signal attenuation in areas with interference

Well-known manufacturers of LPWAN radio modem chips, including the ISM range, such as STMicroelectronics: and Texas Instrument recommend also using a two-beam model to estimate the range of the communication channel [21, 22]. The two-beam model requires a line of sight between the receiver and transmitter antennas. Communication equipment usually operates near the surface of the earth. Therefore, to estimate the range, you also need to take into account the influence of the Earth (simplified form of the formula):

$$P_{2ray}(d) = \left(\frac{\lambda}{4\pi * d}\right)^2 * 4 * \left(\sin\left(\frac{(2*\pi*h_m*h_b)}{\lambda * d}\right)\right)^2 \quad (4.3)$$

The calculation results are shown in Fig. 4.5.

To compare the results, the line-of-sight (LoS) range, which takes into account the limitation of transmission due to the curvature of the earth's surface for a receiving antenna

height of 10 meters and 100 meters (transmitter antenna height of 1 m), was also added to the calculations:

$$LoS_1 = 4.12\left(\sqrt{h_b} + \sqrt{h_m}\right) = 4.12\left(\sqrt{1} + \sqrt{10}\right) = 17 \text{ км}$$

$$LoS_2 = 4.12\left(\sqrt{h_b} + \sqrt{h_m}\right) = 4.12\left(\sqrt{1} + \sqrt{100}\right) = 45 \text{ км} \quad (4.4)$$

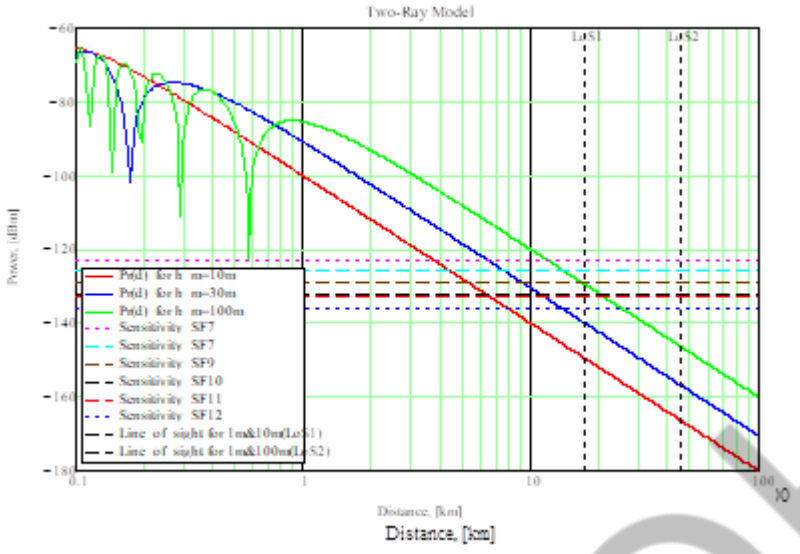

Fig. 12. Dependence of the LoRaWAN radio signal power at the receiver input on the distance to the transmitter (two-beam model)

From Fig. 12 it can be seen that for the selected heights of the antennas (1 m for the transmitting and 10...100 m for the receiving) the influence of wave interference disappears at distances greater than 1 km, so simplified expressions can be used. The maximum distance according to this model was 26 km (SF12, height of receiving antenna 100 m, transmitting antenna 1 m).

Next, the Hata model, which is also called the Okumura-Hata model [23], was chosen for evaluation. This model is used to predict radio wave propagation loss. The essence of the model is to estimate the propagation of radio waves based on the prediction of losses on the way of transmitting information in the propagation medium. The model is based on the use of the three-dimensional SBR (shooting and reflecting beam) algorithm, which is used to determine the paths of rays from the base station to the mobile station in three-dimensional space. Hut's model in the form of a mathematical notation is also based on Okumura's experimental data.

Formulas (4.5–4.7) are used to study the attenuation of the LoRaWAN radio signal in different areas (urban, suburban and rural):

$$L_{urban} = \begin{matrix} 65.99+26.16*\log(f_c)+(44.99-6.55*\log(h_b)*\log(d)-13.82*\log(h_b)-(3.2* \\ *\log(11.75*h_m)^2-4.97 \quad if \quad d \leq 20\ km \\ 65.99+26.16*\log(f_c)+(44.99-6.55*\log(h_b)*\log(d)^{b(d)}-13.82*\log(h_b)-(3.2* \\ *\log(11.75*h_m)^2-4.97 \quad if \quad d \geq 20\ km \end{matrix} \quad (4.5)$$

where: f_c - transmission frequency;

h_b–base station antenna height;

h_m - the height of the antenna of the mobile station;

d - distance between base and mobile stations.

$$L_{suburban} = \begin{matrix} L_{urban} - 2*\left(\log\left(\frac{f_c}{28}\right)^2\right) - 5.4 \quad if \quad d \leq 20\ km \\ L_{urban} - 2*\left(\log\left(\frac{f_c}{28}\right)^2\right) - 5.4 \quad if \quad d \geq 20\ km \end{matrix}, \tag{4.6}$$

$$L_{rural} = \begin{matrix} L_{suburban} - 4.78*(\log(f_c)^2) + 18*\log(f_c)\ if \quad d \leq 20\ km \\ L_{suburban} - 4.78*(\log(f_c)^2) + 18*\log(f_c)\ if \quad d \geq 20\ km \end{matrix}, \tag{4.7}$$

It should be noted that despite the fact that the Okumura-Hata model is a fairly widespread model for estimating the communication range, including for the LoRaWAN protocol [24], it has some limitations in application, in particular: standard indicators of the height of mobile stations in the Okumura-Hata model from 30 to 200 meters, which significantly reduces the adequacy of calculations for a base station below 30 meters and a mobile station above 200 meters, or requires additional experimental studies [25].
We use formula (4.8) to calculate the power at the receiver input:

$$Pr = ERP - L, \tag{4.8}$$

where ERP is the effective radiation power of the transmitter.
The results of the calculations are presented in Fig.13.

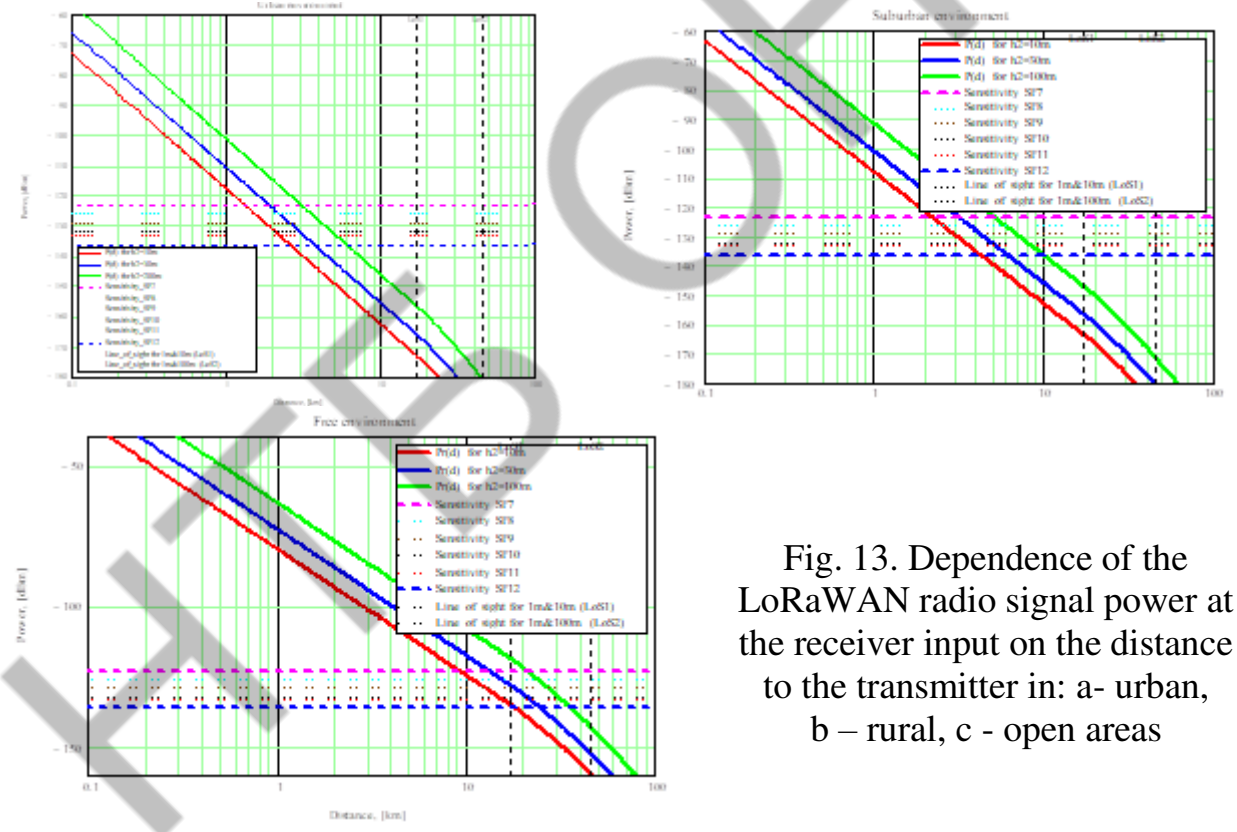

Fig. 13. Dependence of the LoRaWAN radio signal power at the receiver input on the distance to the transmitter in: a- urban, b – rural, c - open areas

It can be seen that when the line-of-sight range threshold is overcome (or near it), the angle of the curve changes, the signal begins to lose power more quickly. The maximum transmission range of the LoRaWAN signal in the open area of the Okumura-Hata model, for the heights of the receiving and transmitting antennas of 100 and 1 m, respectively, is 35 km. As can be seen from Fig. 11 and 13, the signal level at the receiver input calculated according to the Fries formula at a distance of about 5 km coincides with

the values calculated according to the Hata-Okumura model for open terrain with relatively low values of the height of the transmitting antennas (1..3m), but the signal level at longer distances. The obtained results allow us to estimate the maximum distance to the ground base station, depending on the conditions and terrain - 30...40 km,

V.CONCLUSIONS

In the scientific work, the system of backup is proposed emergency communicate on built on the basis of LoRaWAN protocol. A detailed analysis of the organization of such a communication system and calculations revealed the strengths and weaknesses of such a system. In conditions of direct visibility and if available quadcopter slingshots, with the help of which the device for transmitting information can be lifted quite high into the air, LoRaWAN shows extremely good results in terms of transmission range.

To date, the following advantages of the developed system can be said:

- due to efficient energy consumption when transmitting small data packets, the energy consumption level of the end device is slightly around 1 year, for the case of transmitting 100 and receiving 100 messages per day;

-the maximum distance to the base station, depending on the conditions and terrain, is up to 300 km;

- to use the system, it is not necessary to obtain a frequency license and pay for the radio frequency spectrum;

- the construction of such a system is relatively cheap, compared to others with such a transmission range, due to the final cost of the device and the base station;

- with a sufficiently developed LoRaWAN infrastructure of base stations, high efficiency of receiving an alarm message by rescue services.

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GESTURE RECOGNITION USING A NEURAL NETWORK IN REAL TIME

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Abstract. *The aim of this work is to develop and implement a method for gesture recognition. The main functions of the application are capturing images from a web camera, memorizing and recognizing user gestures, and training the created model. Javascript programming language and TensorFlow.js, Jest, Bootstrap, Three.js libraries were used for development. The developed neural network is designed to recognize user gestures, namely recognizing digits formed by hand gestures. The practical use of the developed neural network is determined by capturing the current user's gestures in real time from the video stream, searching for the corresponding gesture of the digit and facilitating user interaction when working with the computer, which is especially important for people with limited abilities.*

Keywords: *Neural network, gesture recognition, digit recognition, real-time recognition.*

I. INTRODUCTION

Image recognition is the process of analyzing graphical data in real-time. That is, any device or system capable of recognizing graphical images can be programmed to automatically respond. Such devices/systems can perform actions without human involvement.

The ability to build such systems is one of the major achievements of the last decade. Nowadays, more and more human spheres are integrating such systems into their processes to increase efficiency or reduce time costs, e.g. medicine or gaming industry.

Techniques for recognizing human posture using sign language are tested for finger and hand position to understand problems in recognizing human gestures. In practice, segmentation of hands and distinguishing gestures from each other are important for achieving higher accuracy. Different models of alphabet and digit classification are used for recognizing sign language. For example, in (Hussain, 1999) an Adaptive Neuro-Fuzzy Inference System (ANFIS) is used for recognizing Arabic sign language. In this proposed technology, color gloves are used to avoid segmentation problems and this helps the system to work towards a good result. Handouyahia is an International Sign Language Recognition System (ISL). The developers used a Neural Network (NN) to study the alphabet. NN is used for such a purpose as recognition as it can easily be trained and trained with functions developed for sign language. Another approach includes the Fourier Descriptor (FD) which is used by Malassiotis & Strintzis for three-dimensional gesture recognition demonstrated by the user's hands. In their system, they used hand orientation and silhouettes for object

recognition. Similarly, Likar and Siroani in 2002 used Fourier coefficients to represent the shape of the hand in their system, which allowed them to analyze hand gestures for recognition. Freiman and Rot in 1994 used an orientation histogram to classify sign symbols, so large pedagogical data is used to solve the orientation problem and to avoid incorrect classification between symbols [1].

With the development of technologies, the medical field is rapidly evolving, and gesture recognition technologies are used in various medical fields, both as assistants to surgeons during complex operations requiring high precision, and for better interaction and creating a more comfortable life for people with disabilities.

Gesture recognition is especially necessary for people with vision and hearing impairments, as well as various diseases related to joints and muscles. Thus, people with poor vision have great difficulty working with a computer, people with hearing problems have problems with socialization and proper integration into society. People with joint problems often experience pain that complicates work with a computer, preparation for tests and exams, writing projects and theses.

The goal of this work is to develop a software application for real-time user gesture recognition using Javascript language, Jest library for testing, Tensorflow.js library, Three.js library, Bootstrap library, which performs the following functions:

- Capturing video images in real-time.
- Memorizing gestures.
- Recognizing gestures.
- Training a neural network model for further gesture guessing.

II. LITERATURE ANALYSIS

Working with images is an important area of Deep Learning technology application. All images from cameras around the world form a library of unstructured data. Using neural networks, machine learning and artificial intelligence, these data are structured and used for various tasks: household, social, professional and governmental, including security.

The basis of all video surveillance architectures is image recognition (object) as the first phase of analysis. Then, using machine learning, AI can recognize actions and classify them.

For image recognition, a neural network must be pre-trained on data. This is similar to the neural connections in the human brain – we have certain knowledge, see an object, analyze it and identify it.

Neural networks are demanding in terms of dataset size and quality on which they are trained. Datasets can be downloaded from open sources or collected independently. Several different AI neural network architectures are distinguished, including neural networks for image recognition:

- Multilayer Perceptron.
- Recurrent Neural Network.
- Recursive Neural Network.

- Long Short-Term Memory (LSTM).
- Convolutional Neural Network (CNN)

For the course project, a convolutional neural network (CNN) architecture was chosen to achieve the goal. CNN reduces the memory requirement for storing information simultaneously, making it better at recognizing high-quality images, repeating objects, edges, texture fragments, etc. This neural network is used in various fields to solve various tasks, such as:

- Image and signal classification. Widely used for MRI diagnostics, disease or symptom classification, in agribusiness neural network helps to recognize images obtained via satellite and further predict crop yield of a particular location.
- Object recognition. Used in unmanned vehicles, video surveillance, "smart home" systems.
- Recognition of a specific equipment brand.
- Three-dimensional facial reconstruction from photographs.
- Face recognition of people. This technology is relevant for the police work. Namely during the full-scale Russian invasion in Ukraine such technology helps to identify russians who have committed war crimes [2].

To train a ZNM model, the following sequence of steps is used:

1. Encode input data as OH-vectors.
2. Pass data to a layer to simplify 2-dimensional data into 1-dimensional.
3. Pass data to a layer with ReLU activation function.
4. Pass data to a layer with Softmax activation function.
5. Optimize algorithm in neural network training using Adam optimizer and optimize loss using categoricalCrossentropy [3].

Neural networks are widely used by companies such as Google, Amazon, Apple, as well as smaller, lesser-known ones. Each company or developer seeks the best ways to overcome and solve the task set before them.

In 2017, Korean company Macron presented its FingerTalk gesture recognition application. To launch the gesture recognition program, the user simply raises their arm in the air, which leads to the automatic appearance of a certain object on the user's arm. Then this object can be thrown or moved in other ways.

FingerTalk is equipped with not only traditional computer vision technology, but also deep learning technology. Based on optimization for mobile devices, it was developed to process gestures even faster on smartphones.

This application captures images in real time and displays them on the smartphone screen. The advantages of this application include the absence of the need for a 3D camera or additional sensors, as well as the ability to "interact" with other objects. Another advantage of the application is that gestures are recognized without the use of auxiliary devices, such as special gloves to control the device, making the application accessible to different segments of the population [4].

Another example is Terabee, a French electronics company, which created an app of

the same name as an example of gesture recognition. It is not only a software product, but also a system of cameras, sensors and detectors for recognizing gestures and their practical application.

For people with certain limitations, who find it difficult to move constantly or temporarily, or those who have difficulty manipulating small objects such as a smartphone or remote control, the app allows them to control various devices with minimal effort. Advantages include practical application of the product [5].

Recognition of gestures is widely used to create prostheses for people who have lost limbs. American scientists have applied AI to ensure high accuracy of control of a bionic hand.

When a patient with a bionic hand connected to peripheral nerves wants to move it, a signal from the brain reaches the same peripheral nerves, where it is decoded. The decoder's task is to correctly interpret the signal in real time and transmit it to the prosthesis as a command to perform the desired action. This "translation" of the signal from the nerves to the prosthesis requires processing a large amount of information, so it is not always done without errors, and AI was used to solve this problem.

Experiments have shown that the technology has certain drawbacks and works unstably. One of the participants in the experiment was even able to play a video game thanks to this development. However, the bionic hand responds to the movements of the fingers of the hand, and best of all – to the movements of the thumb and index finger. The technology will still go through stages of improvement and has great prospects [6].

Considering the great potential of convolutional neural networks for solving the task of image recognition, it was decided to use this architecture of neural network for real-time gesture recognition.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

To recognize gestures in real time, this work decided to use such a neural network architecture as CNN – convolutional neural network, namely the MobileNet model presented by the TensorFlow.js library.

3.1. MobileNet model

MobileNet is a model designed for use in mobile applications, and it is the first mobile vision model from TensorFlow.

MobileNet uses depthwise separable convolutions, which significantly reduces the number of parameters compared to networks with regular convolutions of the same depth. This leads to the use of a simplified version of deep neural networks, yet equally effective in visual image recognition [7].

Figure 1 shows the Mobilenet model based on real-time neural network gesture recognition.

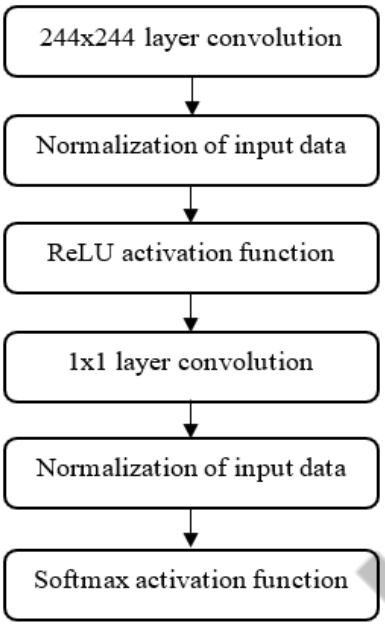

Fig.1. Mobilenet model based on real-time neural network gesture recognition

Folding with a separation depth consists of two operations:

- Deep folding.
- Point folding.

Depthwise convolution originated from the idea that depth and spatial dimension of the filter can be separated – hence the name separable. In this project, an image captured from a web camera in real-time of size 244x244 is fed into the model, thus there are 244x244 input channels. Correspondingly, the same number of output channels as input channels, i.e. 244 channels in this case.

Pointwise convolution is a convolution with channel size 1x1, thus it combines the layers created by depthwise convolution.

After receiving real-time data – images, it is necessary to normalize the obtained data so that the model can further work with them. For this, the image normalization function provided by the TensorFlow.js library is used.

After the model receives all the input data, a training stage is needed for it to be able to perform gesture recognition.

To do this, the normalized input data must first be encoded as an OH-vector. An OH-vector is a unitary code, a group of bits, where the only allowed combinations of values are those in which only one bit is set to (1) and all the others are turned off (0). These vectors are used as target labels during model training.

Then the input data must be sequentially passed through several internal layers, such as Flatten and Dense layers. The RELU function is used as the activation function of the Dense layer. This is one of the most popular functions for deep learning. The logic of the function is as follows: the RELU function returns 0 if it receives a negative argument and the same number if it receives a positive argument.

The RELU function can be represented by the following formula [8]:

$$f(z) = \max(0, z),$$

where z is the argument passed to the function – the input vector.

The next step is to pass the data back to the Dense layer, but with the SOFTMAX activation function, which transforms the vector z of dimension K into a vector σ of the same dimension, where each coordinate σi of the obtained vector is represented by a real number in the interval [0, 1] and the sum of the coordinates is equal to 1. Coordinates σi are calculated as follows [9]:

$$\sigma(z)_i = \frac{e^{z_i}}{\sum_{k=1}^{K} e^{z_k}},$$

Given vector z, with dimension K, and vector σ of the same dimension, the coordinates σ_i of the obtained vector are interpreted as the probability that the object belongs to class i. Vector-column z is calculated as follows [9]:

$$z = w^T x - \theta,$$

where the vector x is a column vector of object features of dimension M × 1, w^T is the transposed matrix of object feature weights of dimension K × M, θ is a column vector of threshold values of dimension K × 1, K is the number of object classes, and M is the number of object features.

Adam Optimizer [10] is used as the optimizer:

$$w_{t+1} = w_t - \alpha w_t,$$

$$m_t = \beta w_{t-1} + (1 - \beta)\left[\frac{\delta L}{\delta w_t}\right],$$

where m_t is the set of gradients, initially $m_t = 0$; m_{t-1} is the set of gradients at time t-1; w_t is the weights at time t; w_{t+1} is the weights at time t+1; α_t is the learning rate at time t; δL is the derivative of the loss function; δw_t is the derivative of the weights at time t; β is the parameter of the moving average (const, 0.9).

To determine the error between expected output data and actual data, the categoricalCrossentropy function is used, which returns a value in the form of an OH-vector.

3.2. The information structure of the system

There are two main objects: user and neural network with which the user interacts. To enable the neural network to recognize user gestures in real time, preparatory steps are first taken, namely – user camera settings, user permission to turn on the camera for further work.

Considering the work of neural networks and the need to train the model, the user must collect data, i.e. images captured by the camera, to enable model training. For this, the user must raise his hand and depict a gesture, in this case a number from 0 to 5, and press the corresponding button with the number of the gesture the user is demonstrating. After clicking the button, the model "remembers" the image and can create a data sample for further model training. The system takes 10 shots after clicking the corresponding button. Of course, the more shots the user takes, the better the neural network will be able to recognize user gestures.

If the user forgot to perform the above-described steps, he will see a message that the model cannot be trained, as it did not receive the sample data it needs for training. After that, the user will still be able to perform the necessary steps for further work.

While capturing images, the model remembers and stores them. Then, when the user enters the required gestures, the model receives the sample, and it is possible to start training the model to recognize gestures. For this, the user needs to press the "Start training" button. After that, the user can show gestures to the camera, and the neural network will make its predictions, "guessing" the user's gestures.

To finish "predicting" gestures, press the "Stop predicting" button.

In order to clearly visualize the course of events and plan the main methods to ensure the uninterrupted operation of the program and its logic, a sequence diagram was created which is represented in Fig. 2.

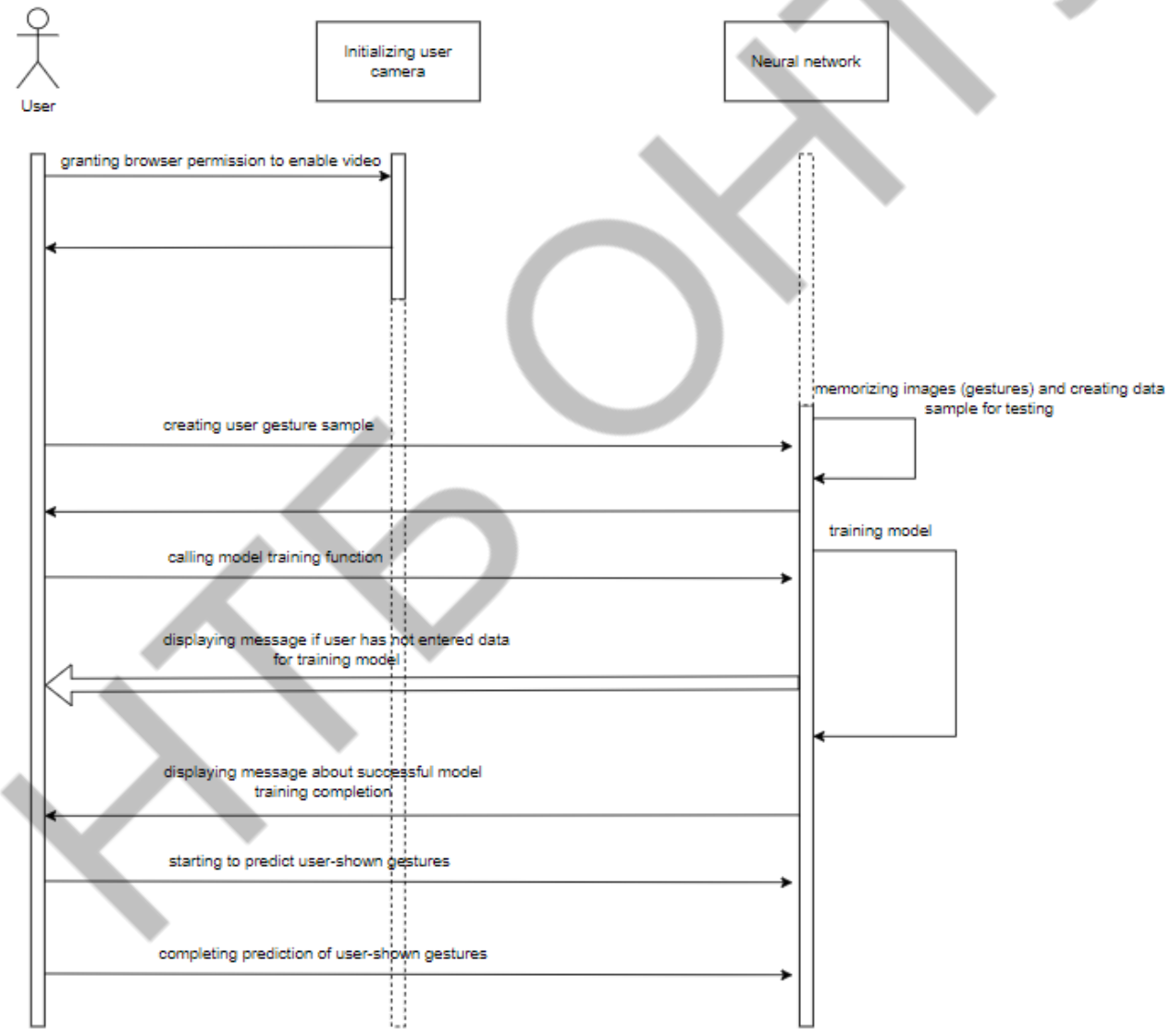

Fig. 2. Sequence diagram of the program

Understanding the application's overall information structure is one of the main requirements for designing a logical, sequential software product, avoiding unnecessary

resource, time or redundant code usage which makes the software solution less understandable and requires more support for the written code.

IV. RESULTS

According to the set goal of the work, based on the previously created structure of the application, a function diagram was constructed (Figure 3).

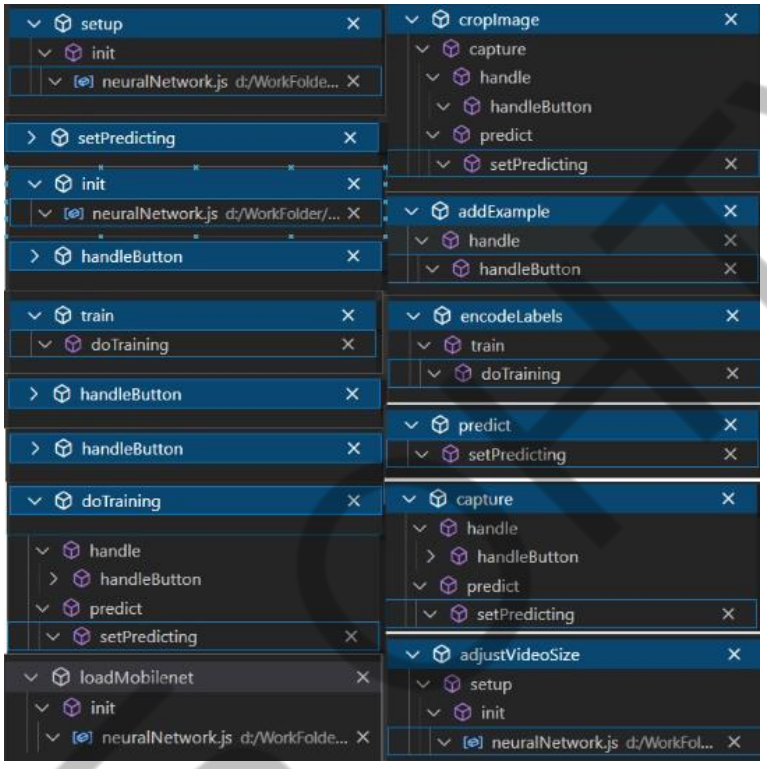

Fig. 3. Function diagram of the program

Each of the used functions has its own purpose and functionality. Some of them perform the logic of the neural network directly, and some are, so to speak, auxiliary functions that help to provide conditions for further work of the neural network.

To ensure proper functioning of the neural network, the user's camera needs to be configured and its size adjusted for correct display on the monitor screen. To do this, a function called adjustVideoSize is written, which takes the video's height and width as arguments. If the video width is greater than the height, the function allows adjusting its width relative to the height and vice versa.

To display the video stream in the corresponding window, the setup function is used. This function receives the video stream from the web camera and also adds a listener to the video element. This listener waits for the video to load and then calls the adjustVideoSize function described above.

The function loadMobilenet downloads the Mobilenet model to create a neural network and train it to recognize user gestures. The function cropImage receives an image from the webcam. It will then be called as a helper function to better process the image

from the webcam and train the neural network.

The next function, called capture, gets an instant snapshot from the webcam and normalizes the data of the received image using the cropImage helper function mentioned above. When the network receives the necessary data to start training the model, the first step is to convert each image into an OH-vector. The encodeLabels function performs this task using the deep learning library Tensorflow.js, which provides flexible tools and methods for working with neural networks.

The training of the neural network is helped by the train function. It consists of three layers: a Flatten layer that takes the input data and helps to flatten it into a one-dimensional vector, a Dense layer with the relu activation function, and a third Dense layer with the softmax activation function, which returns the probability that the gesture shown by the user matches the prediction of the neural network. The AdamOptimizer is used as an optimizer, and the categoricalCrossentropy function is used to determine the error between the expected output data and the real data, which returns a value in the form of an OH-vector. The addExample function receives an image that is passed as a video stream and adds it to the training set for further model training.

To start training the model, the handleButton function must be called, which receives the corresponding element on which the user clicked by the unique element identifier – the button. After the button is pressed, the model will receive 10 samples of the image and add them to the training set. The predict function is used to predict user gestures. It captures an image from the webcam, passes it through the MobileNet model, and then returns the result, which is then used in predicting the current user's gestures.

There are also several helper functions such as setPredicting, which changes the "prediction" state and is used in the predict function, as well as the main init function, which launches the setup and loadMobilenet functions.

For testing the application, several unit tests were created using the Jest library and several functional tests.

Every app must pass certain tests before finding its user. These tests determine the readiness of the created application for release or further testing with the participation of volunteer users. The testing of this program was successfully completed.

The created application is quite easy to use. There are text hints and even if the user performs an unnecessary action or forgets to do something, they will see a pop-up message about what they need to do.

To start using the application, it needs to be launched, then the user will see the program interface.

To turn on the camera, the browser needs to be allowed to use the camera by pressing the "Allow" button.

When the video is loaded, you can start demonstrating gestures. To do this, you need to show a certain gesture, in this case a number from 0 to 5, and press the corresponding button. This step can be done once to teach the model to recognize one number, or for each number. The number of created images will be displayed to the right of the button with the corresponding number (Figure 4).

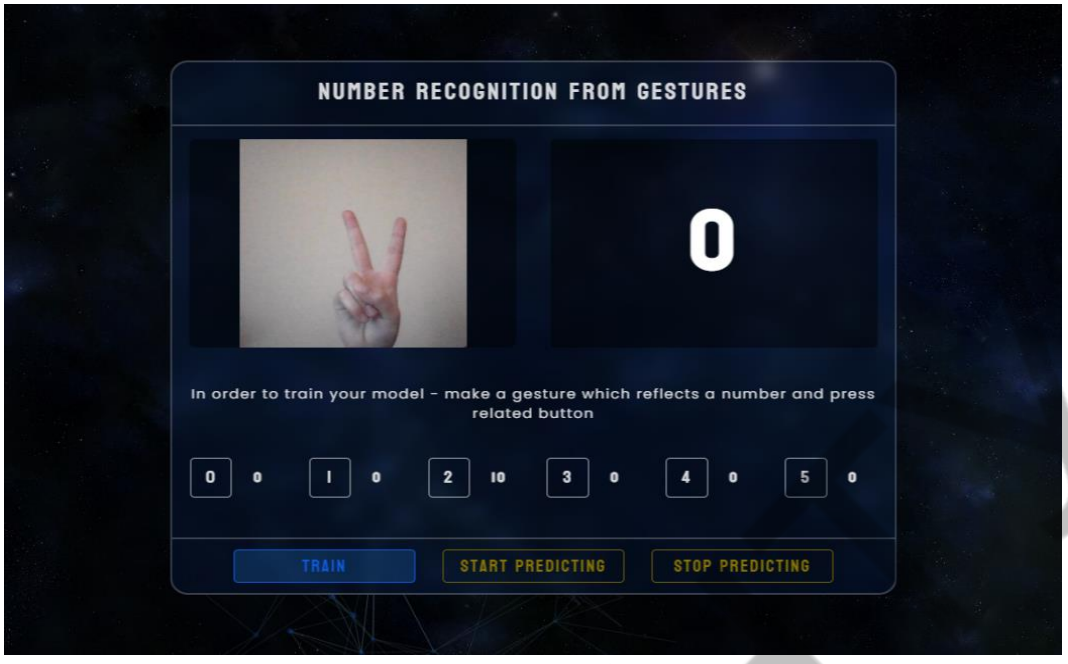

Fig. 4. Gesture demonstration for further modeling training

Once the user has finished demonstrating the gestures, they must press the "Train" button to start the model's training for recognizing the user's gestures in subsequent demonstrations and wait for the message that the model is ready to use.

Now you can start using the gesture prediction app. To do this, press the "Start predicting" button, show the gesture, and the neural network will "guess" the user's gesture, which will be displayed to the right of the user's camera (Figure 5).

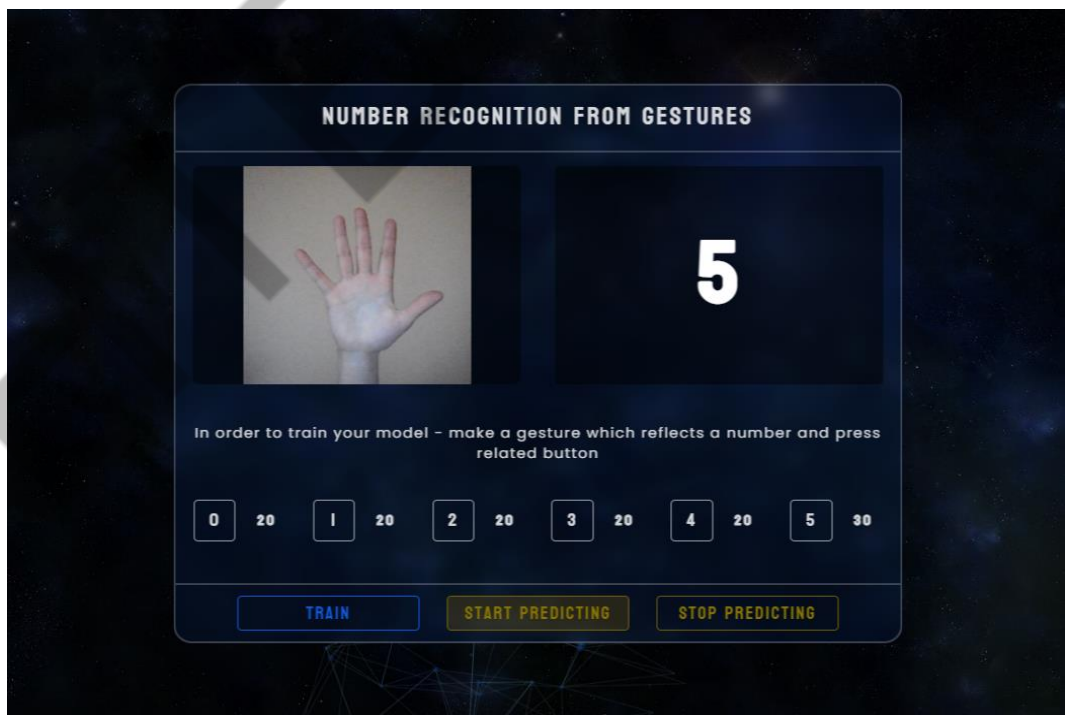

Fig. 5. Result of gesture recognition by a neural network.

To complete the program, press the "Stop predicting" button.

In this way, the real-time gesture recognition method fully fulfills its purpose. The implemented software application is easy to use and contains hints for users.

V. CONCLUSIONS

The purpose of the work was to develop and implement a method for real-time gesture recognition. For the development of the system, the programming language JavaScript was used, as well as the TensorFlow.js, Jest, Bootstrap, and Three.js libraries. As a result of the course project, the theory of artificial neural networks was studied, various types of architectures for solving various problems and various algorithms for creating models using artificial intelligence were considered. In practice, one of the types of artificial neural network architectures was used to solve the task of recognizing gestures in real time.

The use of artificial neural networks is gaining momentum, and this is not surprising, since they help to solve a variety of tasks and problems and make life easier for people. These approaches have been successfully implemented in various fields, such as cyber-policing, automotive industry, medicine.

Technology really has great importance not only in scientific terms, but also for practical application, since neural networks help, in particular, people with various diseases, such as Parkinson's disease, speech or hearing impairments, tunnel syndrome, to facilitate their interaction with the computer, to conduct effective training in schools and universities, and, of course, to socialize.

So, these are only the first steps to make life as easy as possible for people and make it bright, despite certain restrictions.

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INTELLIGENT TECHNOLOGIES OF ASSESSMENT AND MODELING OF THE DEVELOPMENT OF AGRICULTURAL CROPS USING STREAMING DATA PROCESSING OF SATELLITE IMAGERY

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Abstract. *Agribusiness in Ukraine has reached a certain maturity, which is evidenced by the stabilization of the level of investments in agriculture and the growth of competition among producers of agricultural products until the beginning of 2022.*

In the agro-industrial complex of Ukraine, the need for the volume and quality of the use of modern information technologies, in particular systems for collecting, storing and processing data from satellites, unmanned aerial vehicles, sensors of mobile weather stations, has significantly increased. At the same time, both the amount of data and the need for their quality processing and reliable conclusions that can be relied on when making decisions are increasing. As a result, there is a demand for industrial analytical systems and, in particular, advanced analytics.

Within the framework of this project, it is proposed to create a hardware and software information system for evaluating and modeling the development of agricultural crops using stream processing of satellite survey data in order to increase the efficiency and reliability of decision-making processes, diagnose the state of agronomic crops in large areas, optimize the management of agricultural resources, while increasing product quality, bringing significant economic benefits and saving agricultural resources.

The project corresponds to the theme of scientific research and scientific and technical (experimental) developments of the Ministry of Education and Science of Ukraine for 2022-2026 (item 23): perspective technologies of the agro-industrial complex and processing industry.

Keywords: *information system, satellite imaging, diagnostics, agronomic culture, artificial intelligence, precision agriculture.*

I. INTRODUCTION

Land use monitoring is an important task in modern agriculture. Monitoring results are not limited to crop surveillance: they have a wide range of applications from monitoring the condition of agricultural resources, forecasting area and yield, crop assessment to planning harvesting activities and crop preservation [1, 2]. At the same time, the problem of identification of vegetative processes on large agricultural areas during growing cycles is one of the main ones [3].

Classification of the state of agricultural territories is one of the most important agricultural tasks in the world [4]. Due to the increase in food needs (for example, population growth) and the reduction of cultivated areas (for example, the expansion of

cities) in countries importing agricultural products, growing plants requires more and more intensive methods, including triple sowing, the use of modern varieties of seeds, pesticides and fertilizers [5]. However, such intensive cultivation can lead to environmental problems such as water pollution, soil degradation, and microbial damage [6], threatening global food security and national economies.

As a result, those responsible for food safety are looking for solutions for sustainable agricultural production, starting with crop area monitoring and planning to obtain highly accurate information about the condition and location of crops at the level of individual fields in regions of interest [7, 8]. Indeed, in-depth knowledge such as the frequency of price increases and the estimation of production areas can help the government in formulating policies and justifying exports.

In the agro-industrial complex of Ukraine, the need for the volume and quality of the use of modern information technologies, in particular systems for collecting, storing and processing data from satellites, unmanned aerial vehicles, sensors of mobile weather stations, has significantly increased. The topicality of the topic is emphasized by current industry normative documents, in particular, the topic of scientific research and scientific and technical (experimental) developments of the Ministry of Education and Science of Ukraine for 2022-2026 (paragraph 23): perspective technologies of the agro-industrial complex and processing industry.

Under such conditions, the implementation of a software-hardware information system for evaluating and modeling the development of agricultural crops using streaming data from satellite imagery makes it possible to increase the efficiency and reliability of decision-making processes, diagnose the state of agronomic crops in large areas, and optimize the management of agricultural resources, which at the same time increases the quality products, provides significant economic benefits and savings of agricultural resources.

II. LITERATURE ANALYSIS

Traditional systems for monitoring and planning vegetative processes are based on field observations [9]. This method of data collection requires an extremely high expenditure of time, money and human resources. In addition, agricultural areas are not static: they are subject to cycles of cultivation of different types of crops, weather conditions and climate change [10]. Therefore, methods of monitoring and planning vegetative processes based on field observations are too resource-intensive and slow.

Recently, monitoring systems in agriculture have been developed based on modern technologies of remote sensing using satellite data, which are able to meet the existing requirements for the cost and speed of mapping agricultural areas.

2.1. Satellite survey platforms

Satellite imagery is often inexpensive or even free has a wide spatial range covering a large geographic area, and has high temporal resolution (available throughout the year).

Remote sensing is a profitable solution for mapping land resources worldwide due to cheaper data collection compared to field work [5-7, 11]. At the same time, optical satellite sensors such as SPOT (Spot Image, France), Sentinel (European satellite system), and Landsat (National Oceanic and Atmospheric Administration, USA) are widely used. These sensors distinguish between land and crop areas, observing the Earth's surface mainly in the spectral range of 0.4-2.5 μm.

It is known that the use of several data sources, including radar time series, significantly improves the accuracy of mapping [11]. This approach is widely used around the world as a composition of satellite images in several spectral bands (for example, red, blue, and infrared).

In addition, existing methods of mapping agricultural areas based on satellite images often use artificially created spectral characteristics, namely vegetation indices.

2.2. Spectral characteristics

Due to the multispectral nature of satellite images, scientists have proposed different image indices for differentiating cultivated areas from non-cultivated areas [6, 7], vegetation states of plants, and conditions of their development. However, these indexes require a great deal of expert knowledge in manual processing. Existing technologies of automatic image processing, such as VGG, often work poorly on spectral images [9] but give significant errors due to the lack of statistical information and expert assessments for the territory of Ukraine.

The problems of remote sensing in general and satellite images, in particular, are different. First, although satellite images cover a large geographic area, they often have a relatively low spatial resolution, especially for older-generation sensors, resulting in inaccurate estimates of rice plantation areas.

Second, satellite images often suffer from adverse conditions such as cloud shadow or solar radiation [12].

Third, images are often produced by satellites in a polar orbit with a low sampling rate, which prevents 24-hour use.

Last but not least, existing spectral indices for vegetation identification in satellite imagery are empirical in nature and thus require further calibration and validation for different geographic regions and plant species.

2.3. Methods of machine learning

Overcoming these problems is possible only by creating a powerful information system for the automated processing of large volumes of data received from the satellite, data that is stored for a long period of time and forms a "history" of observations and expert data.

Solving the problem of data processing using traditional methods of mathematics and statistics is very difficult, therefore, this work uses an approach for evaluating and modeling the development of agricultural crops using streaming data processing of satellite imagery based on machine learning methods, primarily using convolutional

neural networks.

Deep learning, in particular deep neural networks [4, 5, 12], has been successfully applied to image data analysis, such as image classification, object detection, and semantic segmentation [13].

Due to these successes, deep learning methods on satellite images for land use classification have recently been applied in various remote mapping studies [13-15].

Therefore, the goal of the work is to increase the efficiency and reliability of the processes of diagnosing the state of agronomic crops using machine learning methods based on streaming data from satellite surveys of large areas.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The object of research is the process of diagnosing the condition of agronomic crops.

The subject of research is the means of the information system for diagnosing the condition of agronomic crops and methods of machine learning based on streaming data from satellite surveys of large areas.

Convolutional neural networks, which implement the popular idea of "deep learning" when building intelligent data processing systems, were chosen as a machine learning method to increase the efficiency and reliability of the processes of diagnosing the state of agronomic crops based on the streaming data processing of satellite surveys of large areas.

The intelligent data processing system itself is a streaming data processing pipeline using a neural network (Fig. 1).

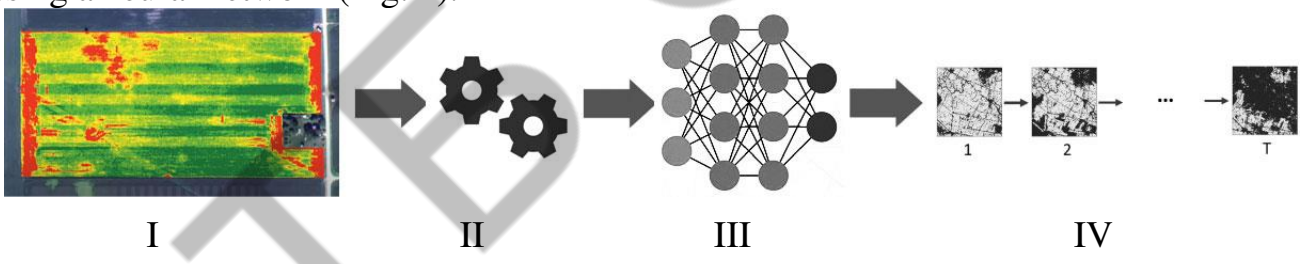


Fig. 1. The structure of the intelligent data processing system in the form of a streaming pipeline of data processing using a neural network.

The multi-level nature of the deep learning neural network architecture will enable the collection of multi-spectral information from satellite imagery in both spatial and temporal dimensions (I). The input data goes to the data processing pipeline (II). The proposed deep neural network (III) is trained on the basis of input data in the form of satellite images in several spectral ranges (Fig. 2). At the output of the system, classification of plant conditions on each fragment of the land plot (IV) is performed according to the existing patterns (training sample).

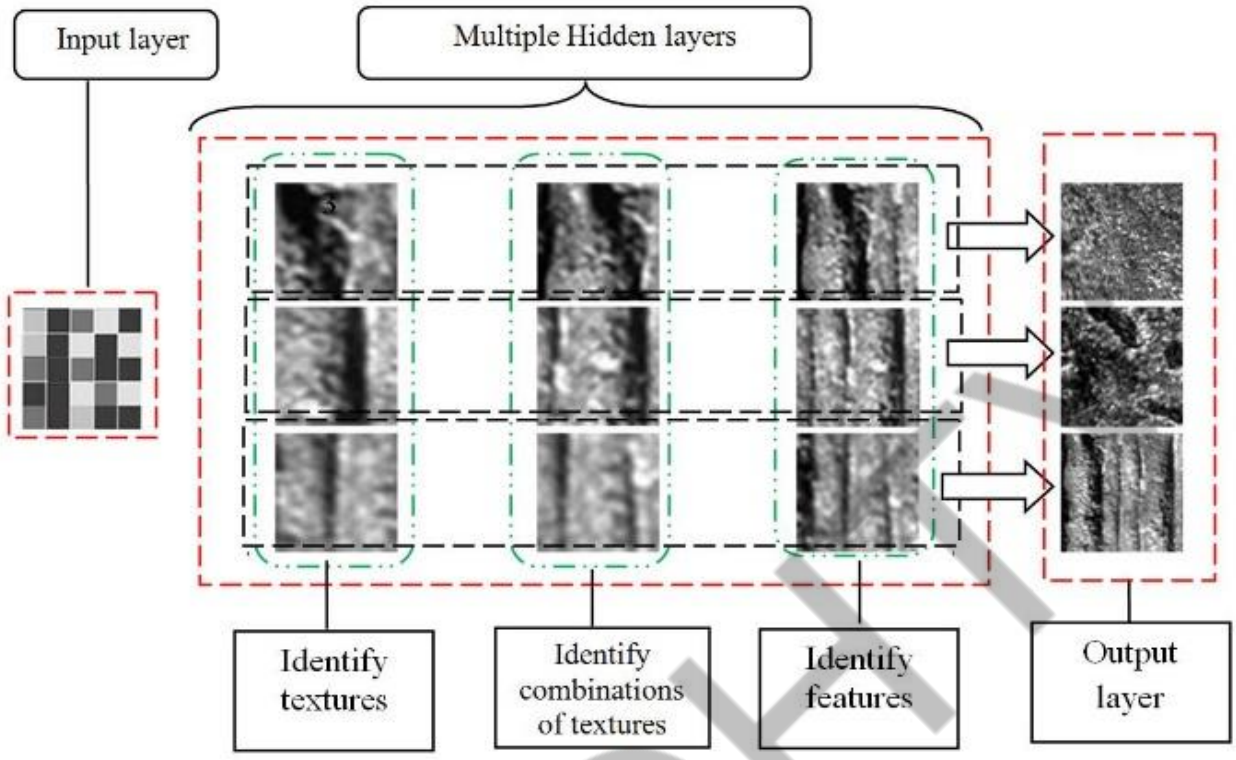


Fig. 2. The structure of a deep neural network that learns on the basis of input data in the form of satellite images in several spectral bands.

The paper proposes the use of a spatio-temporal-spectral deep neural network, which captures time dependencies at several time steps in the past and future directions using hidden layers, captures spatial patterns using convolutional layers, and captures spectral patterns to determine the location of abnormal areas at the pixel level using upsampled layers.

The given structure successfully performs the tasks of collecting data streams from satellite image sources and cleaning from obstacles such as cloud shadows, different angles of the sun's zenith position, and spatial discrepancies and does not require data preprocessing. Such a network is able to generalize spectral, spatial and temporal dependencies without relying on any predefined indices.

To create a powerful classifier with a relatively short training time, the convolutional neural network architecture was chosen and GoogLeNet was adopted. This architecture was proposed by Google specialists in 2014 in a research paper [16, 17].

The GoogLeNet architecture is very different from previous state-of-the-art architectures such as AlexNet and ZF-Net. It uses many different types of techniques, such as 1×1 convolution (to reduce the number of parameters (weights and biases) of the architecture) and global average pooling (reduces the number of parameters to be trained and improves the accuracy of the solution), which allows for a deeper architecture .

The general architecture of GoogLeNet consists of 22 levels (Fig. 3). The architecture is designed with computing efficiency in mind. The idea is that the architecture can be run on individual devices, even with small computing resources.

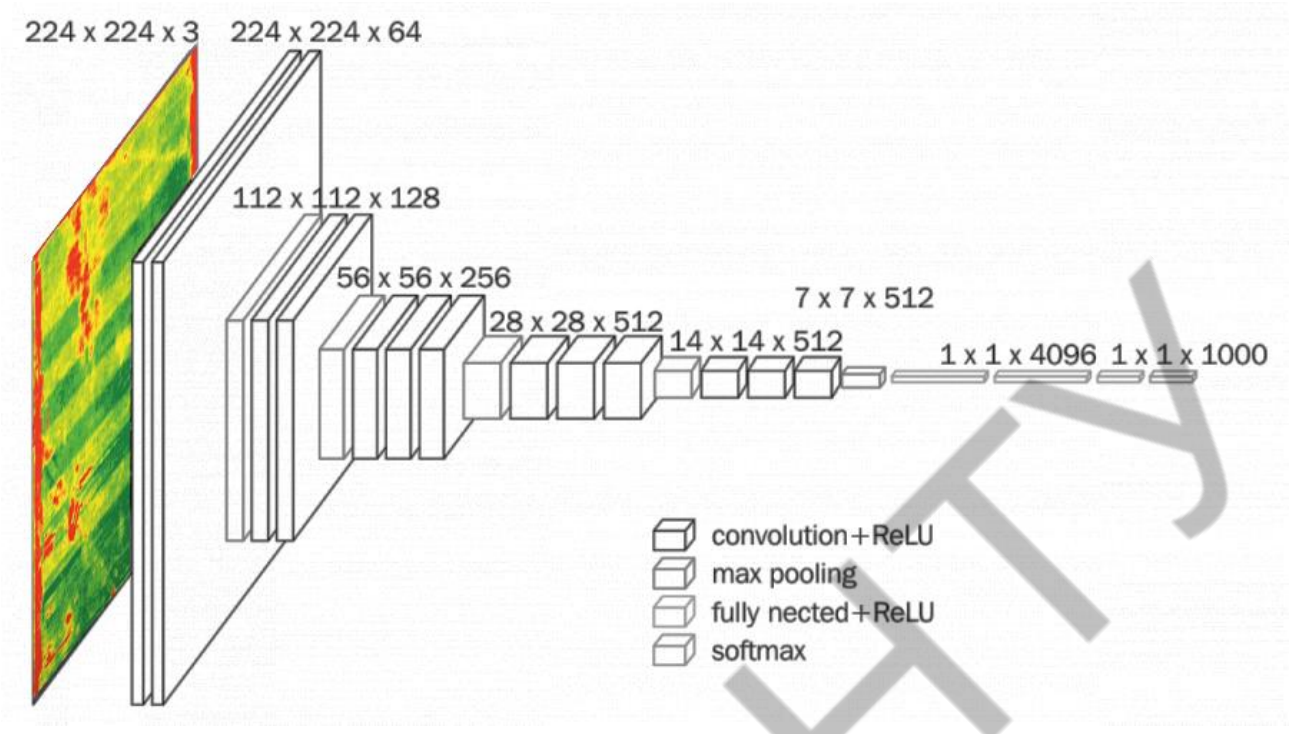


Fig. 3. General Architecture of GoogLeNet Convolutional Neural Network.

The initial architecture can be used in computer vision tasks that involve the use of convolutional filters.

In convolutional neural networks, a large part of the work is choosing the right layer to apply among the most common choices (1x1 filter, 3x3 filter, 5x5 filter, or max pooling). All we need is to find the optimal local design and repeat it spatially.

As these "initial modules" overlap, their output correlation statistics will inevitably change: as features of higher abstraction are captured by higher levels, their spatial concentration is expected to decrease, assuming that 3×3 and 5×5 Convolutions should increase when we pass to higher layers.

In our case, the GoogLeNet architecture accepts a 224 x 224 image with RGB color channels. All convolutions inside this architecture use Rectified Linear Units as their activation functions. So, the network operates with tensors (224, 224, 3) as input data. The model processes the input image and outputs a vector of 1000 values y=(y0, y1, …, y999). The vector y represents the classification probability for the corresponding class.

GoogleNet is trained using distributed machine learning systems with little parallelism of models and data. Asynchronous stochastic gradient descent with a momentum of 0.9 and a fixed learning rate schedule was used during training.

The results of the work of the proposed neural network are given in section IV when solving the problem of classifying the condition of plants according to vegetation indices, which are determined using satellite images in several spectral ranges.

IV. RESULTS

In this work, the Sentinel platform was chosen as the base due to its high spatial resolution. In addition, its database contains archival data since 1999. Another advantage of this platform is its low time resolution (16 days), which is much smaller compared to reclamation cycles [3].

Access to the data received by the Sentinel satellite platform for research is provided by the Center for Satellite Land Monitoring of the Odesa State Agrarian Academy.

In fig. 4. shows the appearance of satellite images in two spectra: visible and infrared radiation.

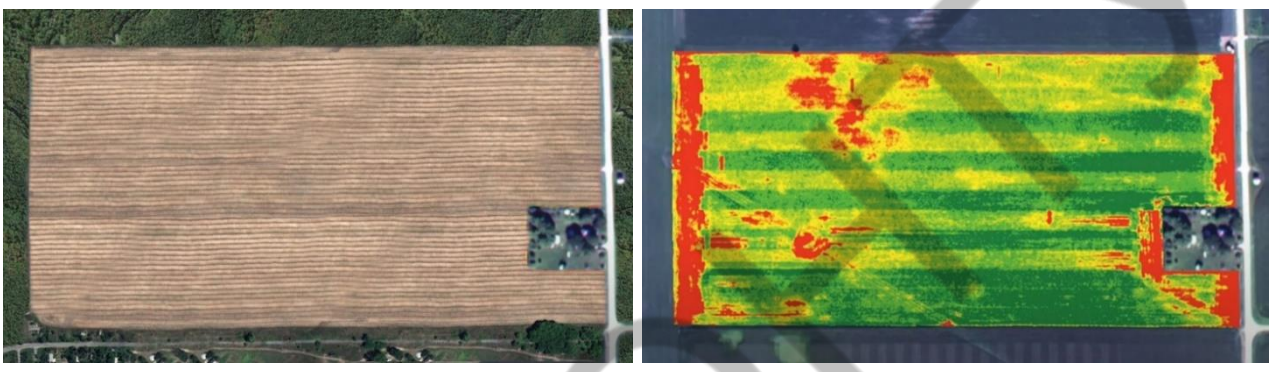


Fig. 4. View of satellite images in two spectra: visible and infrared radiation.

4.1. Formation of the educational sample

As vegetation indices (artificially created informative spectral characteristics) are included in the training sample, 5 known values are used in the work [5, 6].

1. Normalized Vegetation Diversity Index (NDVI) (calculated from near-infrared light reflected by vegetation and visible light; intended only to detect living vegetation, as healthier and stronger plants absorb more visible light and reflect more near-infrared light).
2. Land Surface Water Index (LSWI).
3. Soil-adjusted vegetation index (SAVI).
4. Enhanced Vegetation Index (EVI) (uses additional wavelengths of light to reduce NDVI inaccuracies, including solar incidence angle, light distortion and refraction, and noisy ground signals).
5. Plant vegetation index (RGVI).

Another such index is the EVI, which. EVI also allows you to track changes over time.

4.2. Study of data distribution

In order to extract informative data from the stream of satellite images, a preliminary study of the spectral characteristics of the data must be conducted. In fig. 4 shows the distribution of indices included in the training sample formed on the basis of satellite images. From these distributions, the most informative indices can be established, on the basis of which a classifier of plant states based on a neural network is built.

It can be seen that each index has its own contribution to the identification of plant states. The most informative for the process of diagnosing plant conditions are the NDVI and RGVI indices. Therefore, based on the spectral characteristics of the indices in question, shown in fig. 5, the indices: NDVI, RGVI were selected for the further formation of the training data sample.

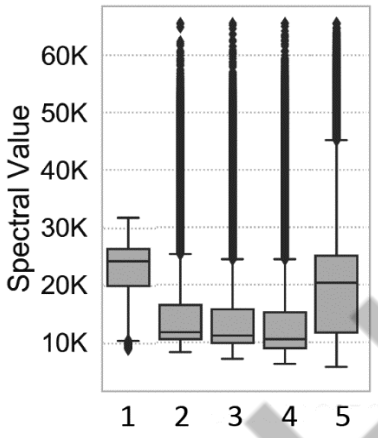
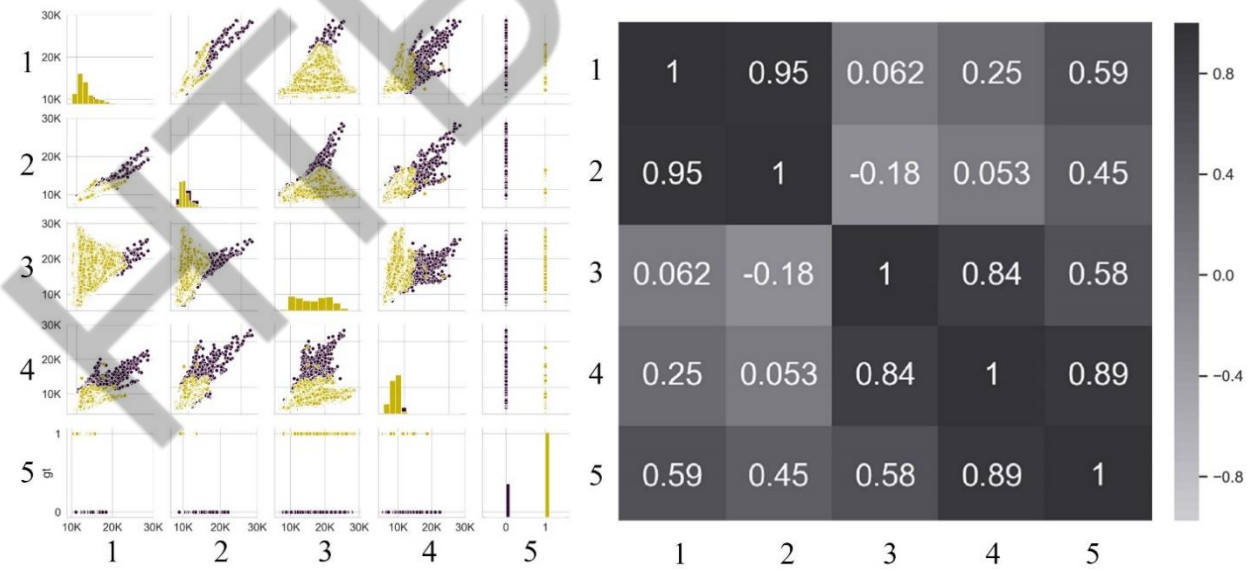


Fig. 5. Value distribution of spectral channels.

4.3. Study of spectral data correlation

To understand the relationship between any two spectral bands, as well as their own distribution, the work uses paired graphs. In fig. 6a shows the pairwise correlation of data for all indices considered in the work. In fig. 6b shows a correlation map in the form of a table of correlation coefficients between pairs of indices.



a b

Fig. 6. Correlation of spectral bands: a – in spectral channels (on satisfactory – dark, unsatisfactory vegetation – light), b – spectral Correlation

4.2. Construction of a neural network classifier of plant vegetation states

The GoogleNet deep neural network architecture, discussed above, is used to build a plant vegetation state classifier that combines spectral, spatial, and temporal information simultaneously.

The input data of the network consists of mxn pixel matrices for each spectral band (each pixel represents a real geolocation), where m and n are the sizes of the region of interest. In our case, the size mxn is equal to 1x1 meter.

The input consists of lxp pixel matrices for each spectral band, where l and p are the size of the region of interest. In our case, the lxp sizes is 10x10 meters.

The GoogleNet convolutional neural network architecture is implemented on the Keras platform using the TensorFlow library (as a backend for Keras).

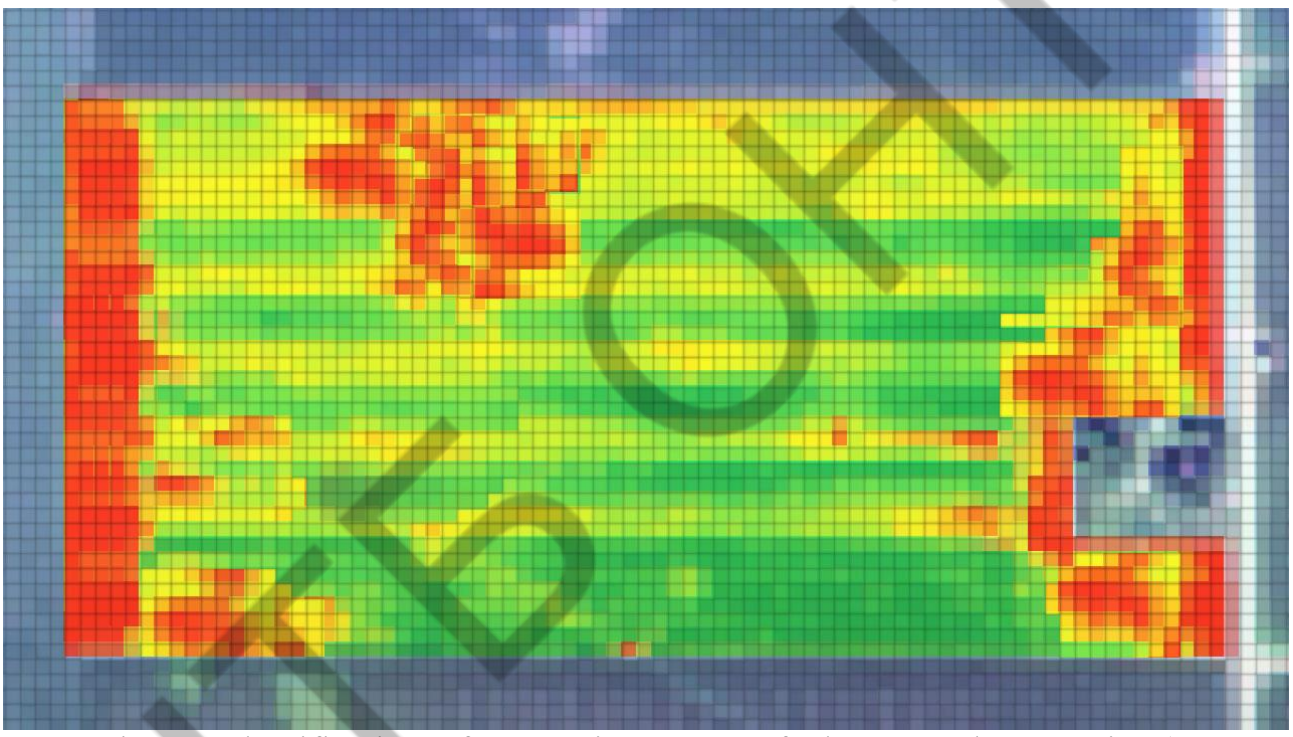


Fig. 7. Classification of vegetation states of plants on the test site (green ¬¬– satisfactory, red – unsatisfactory vegetation)

Graphs of neural network training on the training sample of plant vegetation states on the test site are shown in fig. 8. The classification accuracy was 93.39%.

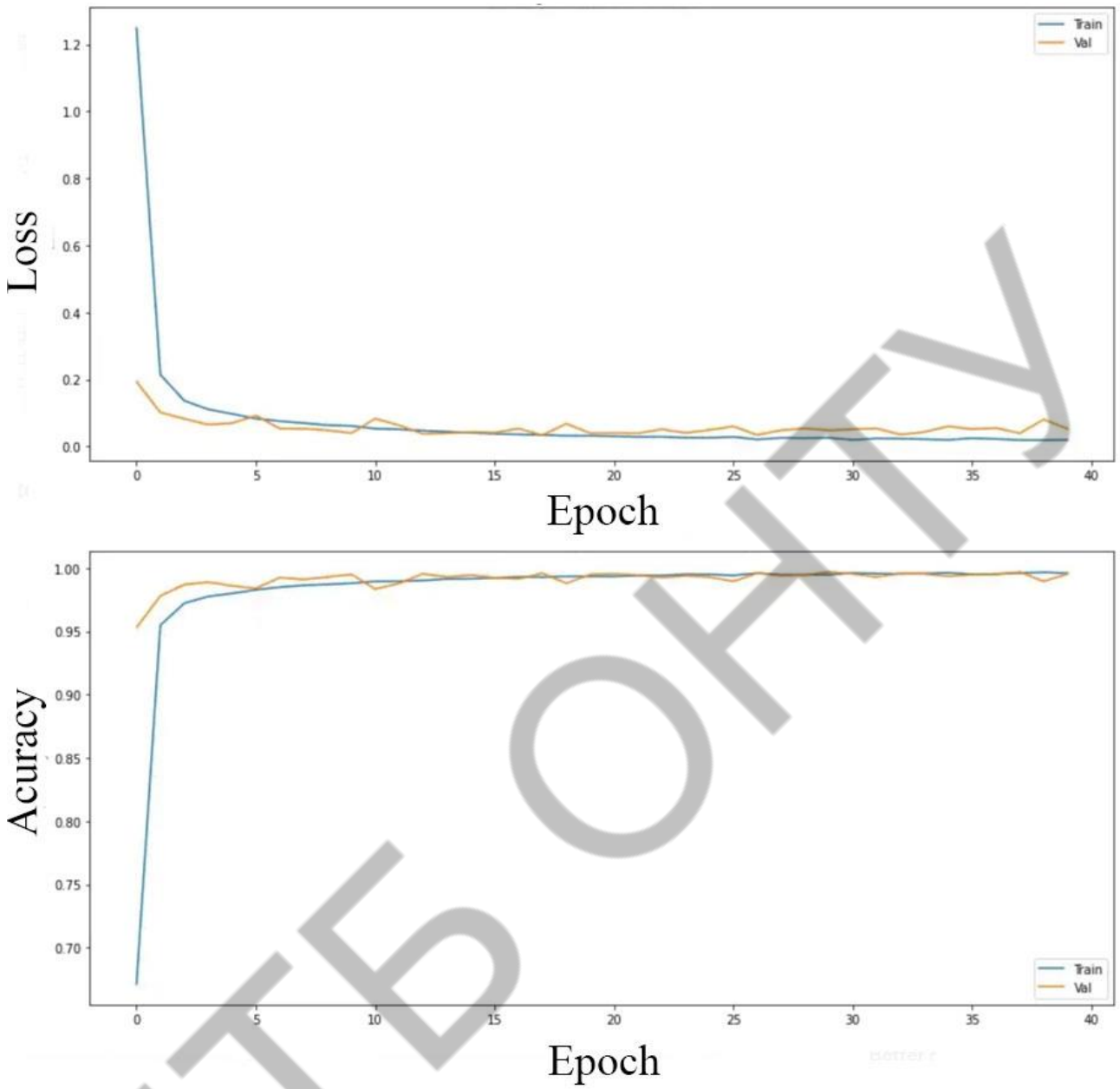


Fig. 8. Training of a neural network on a training sample of vegetation states of plants on the test site: a – training and validation loss; b – training and validation accuracy

Numerical characteristics of the process of building a neural network classifier (training time, testing time, classification accuracy) in comparison with the method of field observations are given in Table 1.

Table 1. The precision, training times, and testing times on the plants' vegetation dataset

Methods	**Training time**	**Testing time**	**Precision**
Neural network	9.8 hrs	6.1 s	0.9339
Field observations	-	-	0.7702

Table 1 summarizes the reliabilities of diagnosing the conditions of agricultural plants on the test plot, obtained by processing satellite images with a neural network and evaluated using field observations. At the same time, the table does not show the training and testing time of the classifier for the field observation method due to the lack of this data. But these values, according to expert assessments, clearly exceed the values obtained for the neural network up to ten times.

It can be seen from the table that the method of determining the state of plant vegetation using satellite photography has advantages in accuracy by 16% and speed by 5-10 times (according to expert estimates) compared to traditional field observations.

V. CONCLUSIONS

The work proposes the creation of a software and hardware information system for evaluating and modeling the development of agricultural crops using streaming data from satellite surveys in order to increase the efficiency and reliability of decision-making processes, diagnose the state of agronomic crops in large areas, optimize the management of agricultural resources, while increasing the quality of products , bringing significant economic benefits and saving agricultural resources.

The information system consists of two main components: stream data processing for collecting and cleaning raw images from adverse conditions of satellite images and multi-temporal mapping with high spatial resolution using a classifier based on a deep learning neural network for automatic fixation of features (diagnosis) of vegetation of agricultural plants.

The conducted simulation of the development of agricultural crops using the streaming processing of satellite survey data demonstrates a significant increase in the efficiency and reliability of the process of diagnosing the condition of agronomic crops on the test plot in comparison with the method of field observations. The implemented approach to determining the state of plant vegetation using satellite imagery has the advantages of 16% accuracy and 5-10 times faster (according to expert estimates) compared to traditional field observations.

Although this work is focused on increasing the efficiency and reliability of the processes of diagnosing the state of agronomic crops in Ukraine, the implemented approach is sufficiently general for other regions for full national planning.

The developed system has profound implications for government officials and agricultural managers and other decision-makers who strive for sustainable agricultural production.

The work can be continued in several directions. First, the diagnostic process can be improved by using additional vegetation indices to increase the level of reliability of mapping. Secondly, the proposed assessment of the condition of plants in large areas can be applied to other, non-food crops (for example, forest fire monitoring, water resources dynamics, etc.) for sectoral and national planning.

The author's contribution can be summarized as follows. The author implemented the software part of the information system for evaluating and modeling the development

of agricultural crops using streaming data from satellite imagery. As a classifier of vegetation states of agricultural plants, the use of a deep learning neural network is proposed. A training sample of satellite multispectral images was formed for the test agricultural area (Odesa region, Ovidiopol district, geocoordinates of the area: 46.287396, 30.439197) and simulation of the development of agricultural crops in this area was carried out using streaming data processing of satellite images.

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DEVELOPMENT OF AN INFORMATION AND TECHNICAL SYSTEM FOR THE EXCHANGE OF MEDICAL DATA WITHIN A MEDICAL INSTITUTION

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Abstract. *The work is devoted to the development of an information and technical system for the exchange of medical data within a medical institution. Such systems help to automate administrative and medical processes and increase the information security of the enterprise. In turn, this increases the quality of patient care and reduces the likelihood of medical errors.*

During engineering, the main problems of modern medicine in the information technologies and of the technical equipment of medical institutions were identified. The object for which the system is being developed has been researched and the task of qualification work has been set.

Modern methods of enterprise organization are analyzed. The main attention was paid to: methods of building small corporate networks, information security and the process of automation of administration.

The process of developing an information and technical system was also described, which includes: the choice of network architecture, software, server and network equipment, and the process of setting up the system.

The result of the work is the developed and implemented information and technical system for the medical institution of KPN "Odesa Regional Clinical Hospital".

Keywords*: corporate network, information security, medicine, automation, software, server and network equipment.*

I. INTRODUCTION

Nowadays, nearly any enterprise uses computer technology in its activities. It can be keeping computer accounting, presenting the company in the form of a website on the Internet, contacting partners using electronic means of communication (e-mail, chat, messengers), automating routine elements of work processes, etc. This thesis also applies to modern medical institutions that produce and accumulate huge amounts of data. The quality of medical care, the general standard of living of the population, and the level of development, in general, depend on how effectively these data are used by medical workers.

There was a need to use large volumes of information when solving medical tasks (diagnostic, therapeutic, statistical, managerial and other). Currently, this determines the creation of information and technical systems in medical and preventive institutions. Until recently, there used to be almost no signs of automation in the health care system of Ukraine. Maps, bulletins, procedural reports, records of patients, medicines - the entire document flow was carried out on paper. It affected the speed and, therefore, the quality

of patient care, complicated the work of medical staff, which led to errors in work, time-consuming filling of cards, and preparation of reports. This complicated the work of the management of the medical and preventive institution.

Therefore, on April 1, 2020, the second stage of the medical reform in Ukraine began. This stage emphasized that all state medical institutions must be connected to the electronic health care system (eHealth) - this is a two-component system that provides the ability to create, review, exchange information and documents between registers, state electronic information resources, and electronic medical information systems.

For this, medical institutions should be carried out with autonomization and computerization. Without this, they will not be able to receive funding from the National Health Service of Ukraine, and this is the most important aspect in the further existence of the medical institution. Consequently, the goal of this project is to develop an information and technical system for the medical institution "Odesa Regional Clinical Hospital". The development and implementation of this project will allow the institution to receive the following benefits:

- Connection to the eHealth system;
- Centralized access to information within the institution;
- Centralized and secure data storage;
- Significant reduction in search time for necessary data;
- Improving the quality and speed of patient care;
- Effective administrative management of the medical facility;
- Transition to electronic document management.

II. LITERATURE ANALYSIS

2.1 Problems of the information and technical component of medical institutions

Modern trends in the market of medical services around the world are closely related to the new opportunities that the progress of information technology provides us. Today, it is difficult to find a modern hospital or medical center that does not use hospital information systems, electronic medical records and, in general, electronic document management for its needs. But, unfortunately, we are talking about modern medical institutions in the West, not in Ukraine. For Ukrainian medicine, it is a common phenomenon when computers, if they are at all in the hospital, are used as typewriters. Needless to say, most specialists have never heard of hospital information systems. It should be noted that the greatest economic and social success is characteristic of those enterprises that actively use modern means of communications, information technologies and their network applications: e-mail, visualization, modeling, computer graphics. But all these applications and related applied tasks require the appropriate qualification of employees, the creation of a new class of telecommunication networks and information resource management systems. Databases, computers, fiber-optic communication lines, personal computers are all components or elements of information systems.

The majority of medical institutions that switched to a new type of financing found themselves in a very difficult situation, their information and technical component was not ready for reform, and had the following problems:

- Outdated technical equipment;
- Insufficient qualified personnel;
- Absence of centralized data exchange;
- Lack of possibility of modernization;
- Absence of information backup regulations;
- Inadequacy of the comprehensive information protection system.

2.2 Analysis of the existing network of the medical institution

Odesa Regional Clinical Hospital has three main buildings: Inpatient Department, Polyclinic and Maternity Hospital. They are combined into one local network using Ethernet and Fast Ethernet technology, data transfer speed in the network is from 10 to 100 Mbit/s. The department of the hospital has a dedicated room for the server (server room).

The local network in these buildings is built using the following network equipment:Медіаконвертори Telstream MC-118/320

- Telstream MC-118/320 media converters
- a PC on which a network OS (RouterOS) is installed;
- D-link dgs-3000-28sc switch in the server room;
- D-Link DGS-1210-28 switch in the server room;
- Switch in the server room TP-Link TL-SG1024;
- Chassis for GateRay media converters;
- Repotec RP switch.

This project will consider the modernization of the LCM of one of the OOKL buildings, namely the building of the polyclinic and the server room. More than 122 medical and administrative personnel work in this unit. But to date, there are only 30 computers in the medical center of the polyclinic, and most of them are not owned by the company.

Most medical staff do not have the ability to exchange information with medical staff in other buildings. All PCs are connected to the Internet through various providers, using outdated network equipment, and Fast Ethernet with a speed of up to 100 Mbit/s is used as a data transmission technology.

The software used by the medical institution mainly consists of operating systems, office packages, tools (antiviruses, disk management, etc.), accounting programs (all together up to 60%), and other (specialized medical software).

2.3 Methods of access to information and its protection

Microsoft Active Directory

Active Directory technology in Windows Server is used to store and organize network objects into a hierarchical, secure logical structure, such as users, computers, or other

physical resources. Active Directory services significantly increase the protection of the corporate network. Yes, all data, such as accounts, are stored on domain controllers that are protected from external access. In addition, the Kerberos protocol is used for authentication in Active Directory services.

Terminal access technology

With the development of local networks for the exchange of information between computers, terminal access was organized, capable of serving several computing processes at the same time. Terminal access - access to the information system, organized so that the local terminal machine does not perform computing work, but only redirects the entered information (from the mouse and keyboard) to the central machine (terminal server) and displays graphic information on the monitor

Virtualization of servers based on hypervisor

Virtualization technologies allow the computing power of the physical server that hosts the virtual machines to be distributed among the virtual machines based on their load. The most common method of implementing virtualization is the use of a hypervisor.

Monitoring of server and network equipment

Modern system administration is ineffective without automated monitoring tools that allow timely response to emergency situations and monitor network dynamics. One of the ways to solve this problem is to implement a system of automated monitoring of network equipment with further analysis of the results obtained during operation.

III. OBJECT, SUBJECT AND DESIGN METHODS

3.1 MODERN METHODS OF ORGANIZING THE ENTERPRISE

3.3.1 Choosing an architecture model

To solve the problem of centralized management and protection of the company's local network, there is a sufficient number of solutions that have different implementations, approaches and different methods of use. In modern realities, the choice of a method for solving this problem depends only on the preferences of the enterprise and the tasks it performs. The administration of the local network can be conducted from a separate cluster of the structural unit of the enterprise, and the entire corporate network can be administered using ready-made solutions for building centralized network management. Despite all the variety of specific implementations of modern information networks, the absolute majority of them have one or another typical architecture as their basis. It is accepted to define several typical
architectures for building information networks:

- terminal-main computer architecture;
- peer-to-peer architecture;
- client-server architecture;
- cloud architecture.

To choose the necessary architecture, it was necessary to analyze the two most common architectures, peer-to-peer and client-server. After analyzing the two architectures, and taking into account all the wishes of the owner of the medical institution, a three-level client-server architecture was chosen, the shortcomings of which are not critical for this institution.

3.3.2 Selection of software

A medical information system - is a document flow automation system for medical institutions, which combines a medical decision support system, electronic medical records of patients, medical research data in digital form, patient condition monitoring data from medical devices, means of communication between employees, financial and administrative information. During the analysis of the market of medical information systems, several leaders were singled out, namely: Health24, Helsi, SimplexMed, Kashtan, Dr. Eleks. Certain criteria were also identified by which MIS should be selected, namely:

- Integration with the eHealth electronic healthcare system;
- Personal doctor's office;
- Connecting DICOM equipment;
- Integration with other MIS;
- Own laboratory subsystems;
- Telemedicine support;
- Availability of the medical statistics module;
- The presence of a warehouse accounting module;
- Availability of the personnel accounting module;
- Electronic document flow;
- Online appointment;
- Type of data storage;
- The cost of purchasing a license.

The results of the comparison of medical information systems for medical institutions according to generally accepted criteria are shown in the table.

Table 3.1

The name of the characteristic	The name of the software product				
	Health24	Helsi	SimplexMed	Chestnut	Dr. Alex
Integration with the electronic healthcare system eHealth	+	+	+	-	+
The patient's office	+	+	-	-	+

Connecting DICOM equipment	+	-	+	-	+
Integration with other MIS	-	-	+	+	+
Own laboratory subsystems	-	-	+	-	-
Telemedicine support	-	-	+	-	-
Medical statistics module	+	+	+	+	+
Accounting of storage facilities	+	-	+	-	+
Accounting module	-	-	+	-	+
Personnel accounting module	-	-	+	-	+
Electronic document management	+	-	+	+	+
Online appointment	+	+	+	+	+
Type of data storage	Cloud storage		Centralized data storage on the enterprise server		
The cost of purchasing a license (one workplace) per month	350 UAH	350 UAH	650 UAH, or 10,000 unlimited	450 UAH	750 UAH

So, after considering the available analogs of MIS, the characteristics of which were given in table 3.1, we can say that the project will be built using the software product "SimplexMed", so it has the following and key advantages over competitors:

- Integration with the eHealth electronic healthcare system;
- Connecting DICOM equipment;
- Centralized data storage on the enterprise server;
- Availability of the medical statistics module;
- Telemedicine support;
- The presence of a warehouse accounting module;
- Own laboratory subsystems

Operating Systems. Different types of operating systems can be seen today on any device that has applications installed, from phones and game consoles to supercomputers

and web servers. Examples of popular operating systems today include Android, BSD, IOS, GNU/Linux, OS X, and Microsoft Windows.

Since the technical requirements of MIS, which support two processors and the Windows family OS, are taken into account during the construction of the ITS, the Windows Server 2022 OS of the Datacenter edition was chosen, it has updated security protocols, support for modern processors and a set of modern modules (RDS, Hyper-V, Active Directory) that will be used in this project.

Given that the client-server architecture, based on RDS, will be used, workstations can use any OS that allows connecting to the central server using the RDP protocol. Since Windows is a paid OS, Linux OS was chosen for the workstations.

Monitoring system. For this project, the Zabbix monitoring system was chosen, which combines modern monitoring methods, a large number of notification methods, and a convenient interface.

3.3.3 Selection of equipment configuration

Server. The choice of technical characteristics of the server depends on the tasks it will perform. It is necessary to highlight the following main tasks:

- RDS support for 500 users;
- MIS support for up to 200 users;
- Deployment of Active Directory.

Let's highlight the critical modules for building a terminal server:

- Number of RAM;
- Number of CPU cores;
- Storage size.

The requirements for the server on which RDS will work were identified through research. A system with one user (administrator) needs:

- 1 CPU core is loaded at 4%;
- 1 GB of RAM;
- 23.2 GB HDD.

Each subsequent user consumes 200 MB of RAM and 300 MB of HDD space, and when the user starts, another 100 MB of RAM is required. MIS consumes approximately 150 MB of RAM during load. Also, users need a place to store work documents.

Thus, taking into account the minimum requirements for the server, and a certain supply of allocated resources per user, for 10 users working at the same time, you need:

- 4.5 GB of RAM;
- 1 CPU core;
- 503 GB (3 GB for system and 50 GB for user files).

So, for 122 users you need:

- 54 GB of RAM;
- 12 CPU cores;
- 6 TB of storage.

Basic minimum hardware and software requirements for deploying Active Directory:

- Availability of at least one node (hardware or virtual) running MS Windows Server;
- 64-bit processor with a clock frequency of at least 1.4 GHz;
- RAM of at least 512 MB;
- System disk at least 40 GB.

Based on the requirements of MIS, RDS service and Active Directory, we will build a table of requirements for the hardware part of the server.

Table 3.2

	Consumer				In total
Parameters	MIS	RDS	Active Directory	Zabbix	
Processor	2 x Intel Xeon 2 Ггц,	12	x64 1.4 ГГц	2	21
RAM	40 ГБ	54 Гб	512 Мб	2 Гб	96.5 Гб
HDD/SDD	2x6TB HDD	6 ТБ	40 Гб	20Гб	18.6 ТБ HDD
RAID controller	0 ,1, 5, 6, 10	-	-		-

So, taking into account all these factors, as well as the software requirements, and the availability of a separate room for the server room at the enterprise, a 1U server of the Fujitsu company was chosen, namely: Primergy rx2530 m5 in the amount of two pieces to build a fault-tolerant cluster.

Picture 3.1- Server Fujitsu Primergy rx2530 m5

Data storage system. Medical organizations have to work with ever-increasing volumes of data and a heterogeneous structure. Therefore, in large medical complexes and regional hospitals, classic data storage systems (SDS) of medium or high level SAN\NAS are usually needed. The IBM FlashSystem 5010 data storage system with a total memory capacity of 105.6 TB was selected for this project.

Picture. 3.2 - IBM FlashSystem 5010

Workstations. Since the ITS will be built on a client-server architecture, "Thin clients" will be used as workstations. After analyzing the "Thin Client" market, one of the leaders of thi market was chosen, it is the Dell Wyse 3040. The Dell Wyse 3040 thin client is an effective solution made in a compact case.

Picture. 3.3 - Thin client Dell Wyse 3040

Choosing network equipment The main criteria for choosing network equipment are price, scalability, security, bandwidth, centralized network management, support for modern technologies, and fault tolerance. Therefore, it was necessary to make technical decisions for the construction of Gigabit Ethernet and 10 Gigabit Ethernet networks in a high-rise building, in which a data transmission network is partially mounted. At the same time, the possibility of connecting to the network of several communication operators was ensured. Taking into account all these parameters, MikroTik CSS326-24G-2S+RM was chosen as a switch, and MikroTik CCR1016-12S-1S+ and CCR 2004-1G-12S+2XS as a router.

V . CONCLUSIONS

During the implementation of this project, all tasks were implemented, which in turn provide the following advantages for the medical institution:

1. Connecting to the eHealth system. This is the most important component in the work of medical institutions. Institutions that are connected to the electronic health care system get the opportunity to participate in the medical reform, which in turn gives the institution the opportunity to receive funding.

2. Eliminates filling out papers. There is no need to duplicate records and enter information into other documents: doctors and staff who have access to the patient's card can get acquainted with the history of his illness, the course of treatment, and the results of research from a single database.

3. Improving the quality of service and reducing the influence of the human factor. Automated document flow allows you to reduce the amount of paper work, successfully

maintain a customer base, relying on current information about research and services.

4. Advantage for patients. Thanks to MIS, patients get access to their data, quickly receive the results of laboratory tests and take them with the doctor. The probability of forgery and loss of medical data is reduced.

5. Reduction of costs for service personnel. Thanks to the implementation of a modern network architecture and the use of a monitoring system, the IT system requires less attention and effort from system administrators. This project was implemented using modern approaches in the field of information technologies, which in turn allows to implement this project in other medical institutions.

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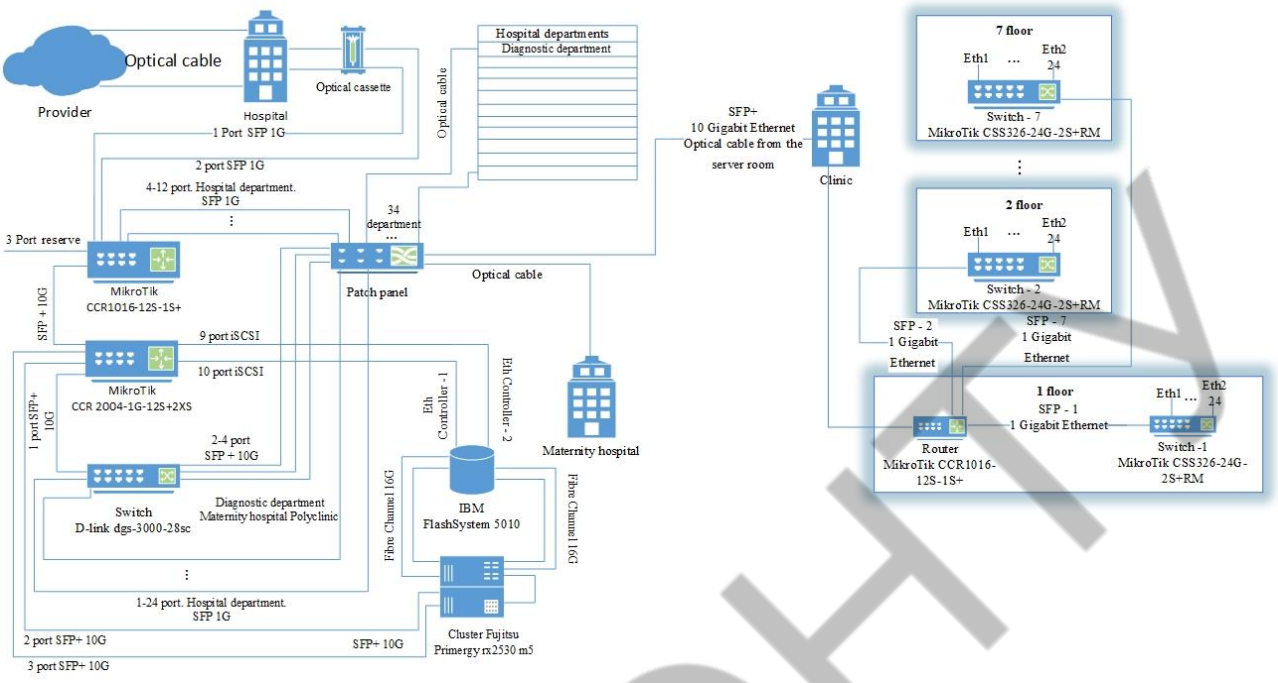
Structural diagram of the projected network



DETERMINING WHETHER A SENTENCE BELONGS TO A SPECIFIC LANGUAGE USING THE METHOD OF ARTIFICIAL NEURAL NETWORKS

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The problem of speech recognition and determining the language of the spoken text is considered. It was concluded that currently there are a number of applications where the method of artificial neural networks is used for language recognition. A neural network model is given. It is specified what data is received at the network input and what transformations were performed on the input data. The key characteristics that were determined experimentally are specified. The results of the model are given.

Keywords: *speech recognition, modeling, persepron, python*

I. INTRODUCTION

Today, there are a number of technical tools that are able to perceive (recognize) messages that are pronounced - computers, medical electronic equipment, cars, mobile phones, etc. There are also many commercial language recognition systems on the market: Voice Type Dictation, Voice Pilot and Viavoice from IBM; Dragon Dictate and Naturally Speaking from Nuance Communications; Voice Assist from Creative Technology; Listen for Windows from Verbex and more. These systems allow you to dictate text documents and manage your computer using voice commands. However, it should be noted that most of them work well only with spoken English [1]. It is argued that two key language recognition tasks are to achieve 100% recognition on a limited set of commands at least for one speaker and independent of the speaker recognition of continuous language flow in real time of arbitrary language with acceptable quality - despite numerous attempts to solve these tasks. over the past 50 years [1].

As a rule, the speech recognition system consists of two models: acoustic and linguistic. The computer records the sound sound in the form of a digital signal, the acoustic model is responsible for converting the language signal to a set of features that show information about the content of the language message. The program performs a complex analysis of the language, comparing audiophragms with the language samples recorded in mention. The linguistic model analyzes the information obtained from the acoustic model and forms the final result of recognition. On the basis of probabilistic calculation, the computer determines what the user could say. The model is based on the concept of phoneme - the smallest acoustic unit of language. In the learning process, the computer recognizes the most important features of the user's pronunciation and records the data obtained as a user profile [2].

Within the framework of language recognition, you can call a separate sub -face - determining the language of the text. It does not matter what the user could pronounce,

and you do not need to select individual phonemes from the said text that simplifies the solution. The development analysis showed a number of applications.

II. APPLICATION ANALYSIS

"Tools for the language of the said text" is a service that defines the audio language. Supports 8 languages (English, Spanish, Italian, French, German, Portuguese, Dutch and Russian), 3 audio formats (WAV, FLAC, OGG). The model uses coagulation and recurrent neural networks, trained for tens of hours of speech data. It is a cross -cutting model that uses the raw signal as input without making assumptions about phonetics or grammar of a language. She tries to conclude all the relevant audio recording functions based on data. The service distributes probabilities from languages that are recognized as the source. Technology can be used to classify records from 1 to 1 minute. It is stated that the accuracy of language definition increases when using longer records. For a 20-second record, the accuracy is about 95%, and for 5-second samples a little more than 80% [3].

Demov version testing showed that in the specified audio (Fig. 1) it is impossible to define language. Sentences were uttered at a moderate pace. None of the proposals was recognized. After that it was decided to use the proposed audiophragms in the languages "English" and "Italian". None of the fragments was recognized. There is no advantage of this service, since the service does not fulfill the key task - does not recognize the language.

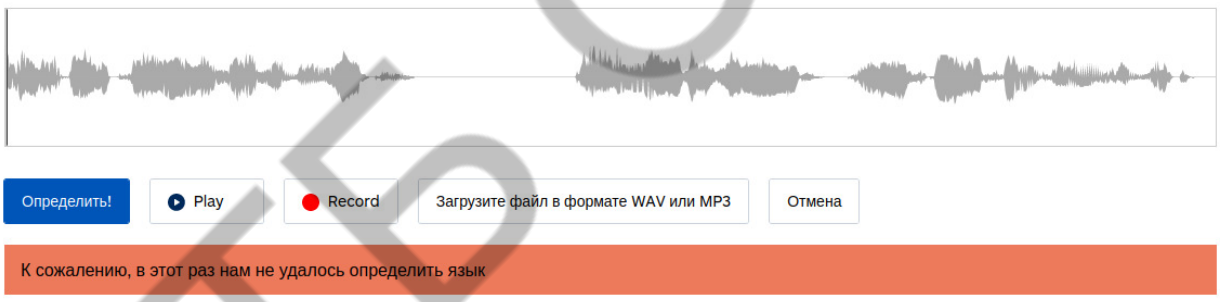

Fig. 1. Screenshot demo version «Tool Define the Language of the Text»

Speech-to-Text: Automatic Speech Recognition-a Google service that allows you to recognize language and transcribe to text. The product is implemented through API based on Google's artificial intelligence technology. Audiodans are sent to speech-to-text, in response, a text type of information sent is obtained. The service is accessed using REST API or using the language console into text. In the documentation, a separate section is devoted to language support. It contains a list of specific language recognition models that are recommended to be applied to certain languages. All of these models can only be applied to 3 languages: English (Singapore), English (United States), French (France) [3].

Demo version test showed that for accurate speech recognition (Fig. 2), it is necessary to pronounce sentences at a moderate pace and without obvious obstacles on the background. English, Ukrainian and Russian were tested. In some cases, punctuation signs were placed during the test. Ten of several proposals were recognized.

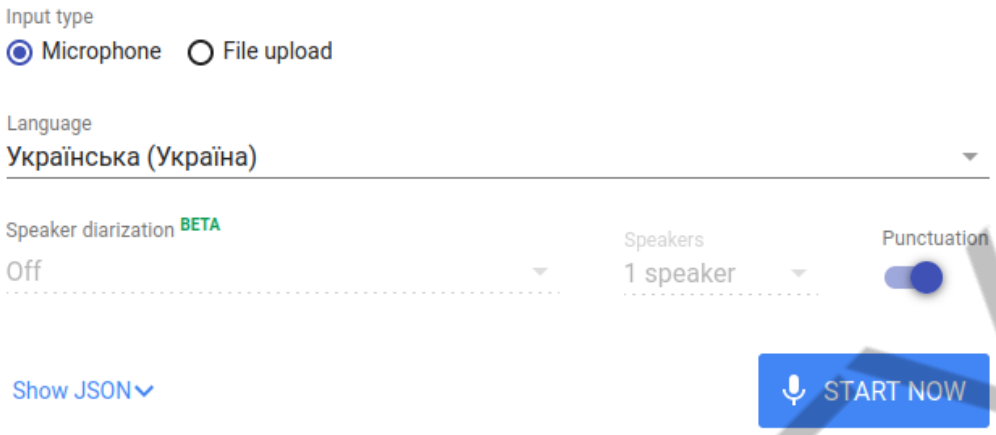

Fig. 2. Screenshot demo version «Speech-to-Text: Automatic Speech Recognition»

The advantages include the following: detailed documentation for installation and subsequent configuration of the API; clear work of the system; possibility of recognition of continuous language; the possibility of recognition of audio files; The whole pool of the languages that are supported. The disadvantages include: closed technology; high cost of product.

«Silero Service» is a service that specializes in language recognition for commercial organizations. The product provides different solutions depending on the needs of the customer. According to the author, the service supports the following languages: Russian, English, German, Spanish. The developers' website presents a demo -version with the possibility of speech recognition of both files (MP3, WAV, OGG) and streaming speech lasting no more than 20 seconds (recognizes only Russian) [3].

Demov version testing showed that the service allows you to recognize the language qualitatively (fig. 3). Only Russian can be tested in demoversion. Short sentences were uttered at a moderate pace. Ten of ten proposals were recognized.

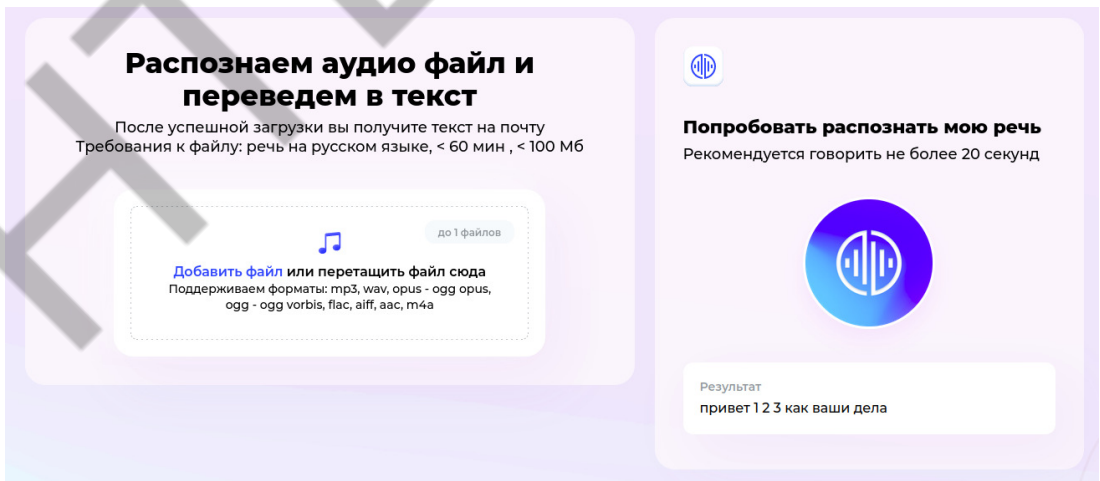

Fig. 3. creenshot demo version «SileroAi»

The benefits can be attributed to:

– the ability to use quality, open API from a commercial service to develop a solution to your task;;

– possibility of recognition of continuous language;

– The possibility of recognition of audio files.

The disadvantages can be attributed:

– closed API (partially);

– only commercial use;

– A small pool of languages.

All the examples considered to determine the language use the method of artificial neural networks. However, there is no specific architecture of the network used anywhere. All described systems are commercial solutions and have high cost.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The development analysis showed a number of applications. All the examples considered to determine the language use the method of artificial neural networks. However, there is no specific architecture of the network used anywhere. All described systems are commercial solutions and have high cost.

The task of developing the information system (first - decision support systems, further mobile application), which allows after the analysis of the voice message recording to determine what language this message was made.

To do this, it is advisable to use Python programming and Pywt, Soundfile, Pickle, Numpy. In the future, there is a possibility of using outsiders open API Silero Service [7].

Network architecture is a multi -layered periceptron that contains n neurons of the input layer, three hidden layers in size (N + 2) each and the output layer in size 2 (fig. 4). The answer is given in the form of probability. The method of reversing errors using a gradient descent algorithm was used to teach a neural network. During the initialization of the neural network, neurons weight is set by randomly, followed by adjustment. Sigmoid feature was used as activation function. The error was calculated by means of an average deviation [4].

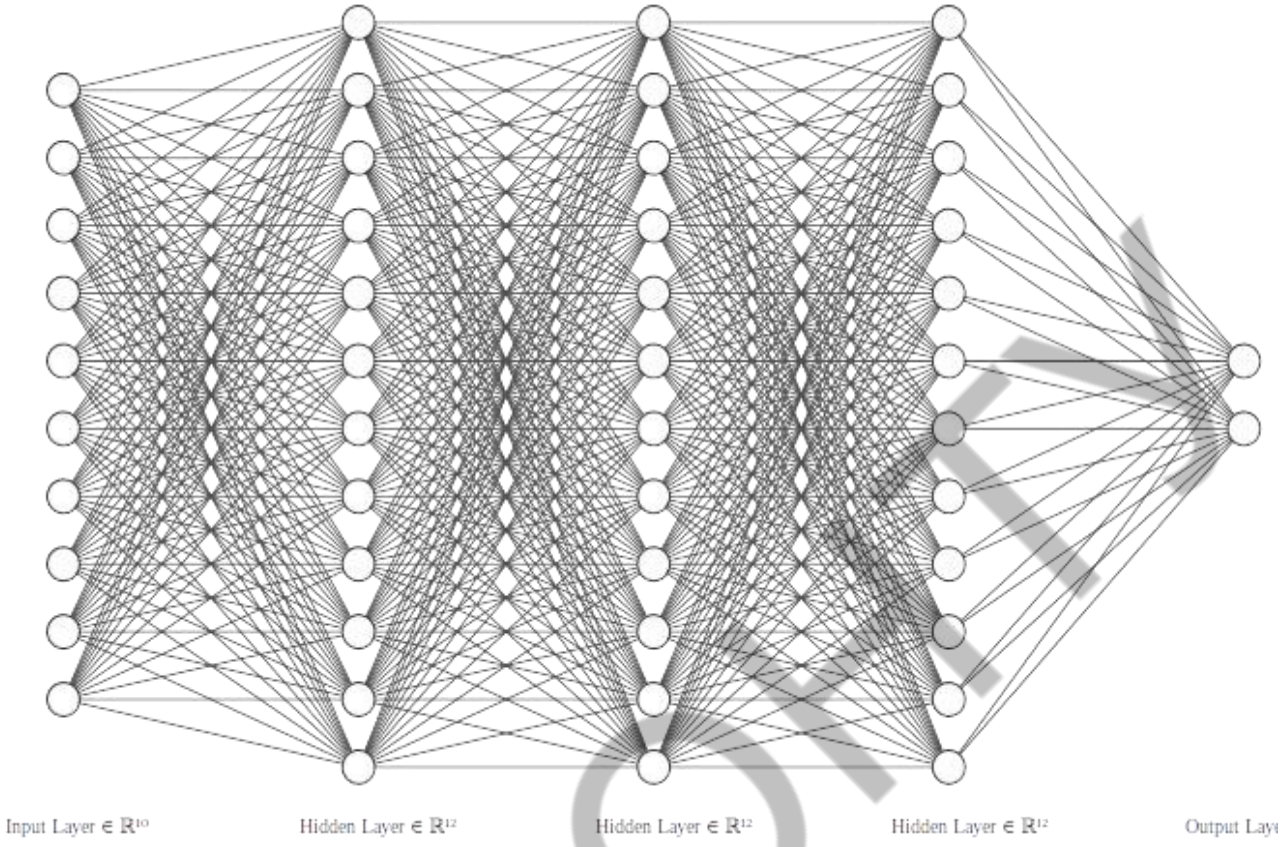

Fig. 4. Example neural network of MLP 10x12x12x12x2

The input data comes as converted discrete values. The conversion implies that discrete values with discrete wavelet transformations were thinned, resulting in the coefficients of approximation and detail. This procedure can be repeated several times. The key parameter is the decomposition level - DL [7]. In fig. 5 shows the block diagram of the values given to the appearance of the matrix.

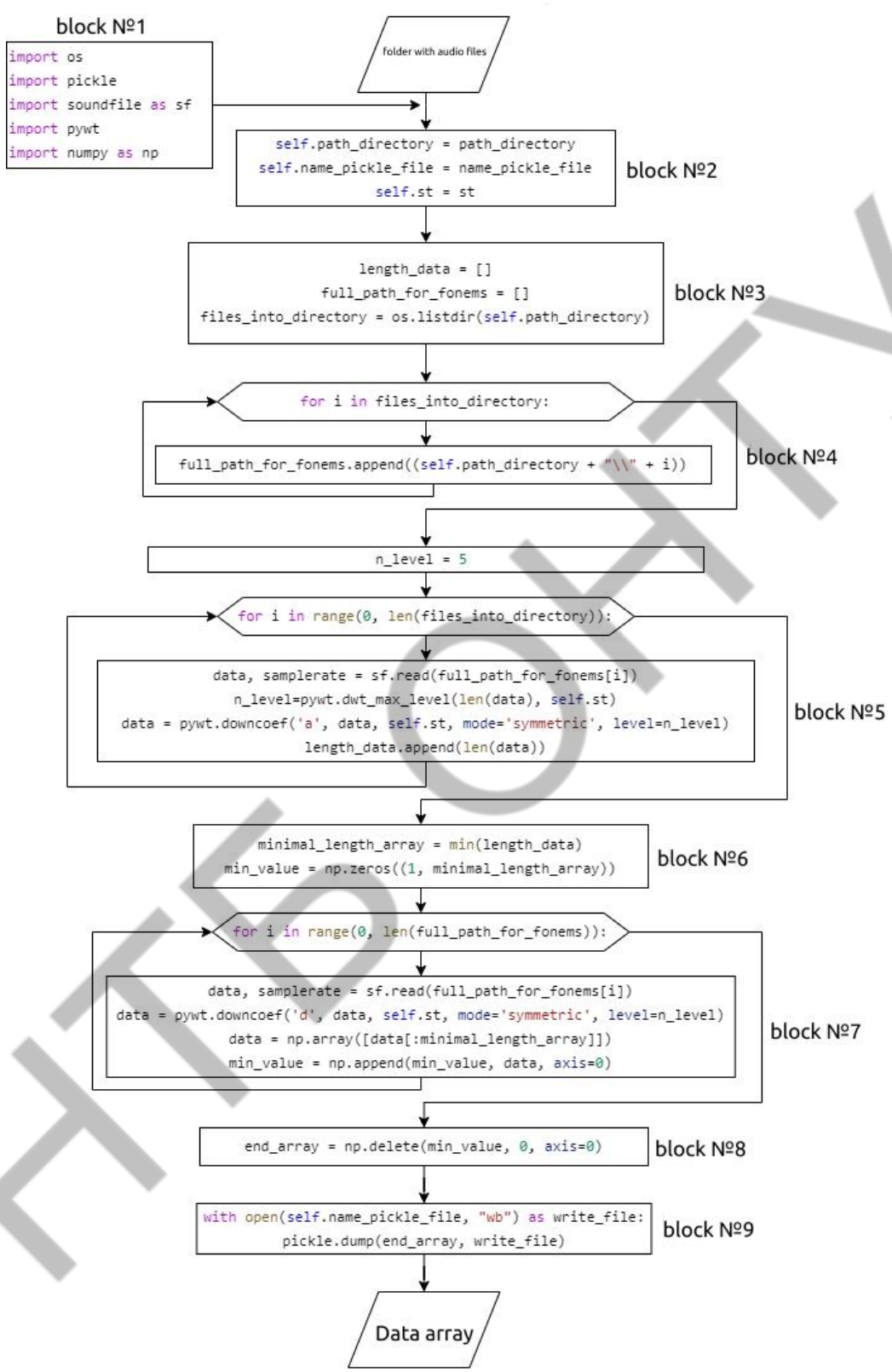

Fig. 5. Algorithm of leaving data to the appearance of the matrix of values

Block №1 - module imports. The OS module is a set of functions that allows you to operate with the operating system. In this case, it is needed to read the file names in the specified Directory. Pickle module is an algorithm of series Python objects. In this case, they are used to pack the already converted data. Soundfile module includes a huge set of features to work with WAV files. In this case, we need to read audio data from WAV files. The Pywt module has a wide range of features to work with wavelet-analysis. In this case, it is needed to obtain approximating values from the auditors obtained using the Soundfile Library. The Numpy module is an extension that allows you to support most multidimensional arrays and matrices. This module will further train a neural network, as methods built into Python will be problematic.

Block №2 - Initialization of input parameters is carried out, as well as the appropriation of a variable copy of the class. The first parameter is the way to the audio base (example: Path_directory = "D: \ Dyplom \ Code \ Test_Data"). The second parameter is the name we want to set the final file (example: Name _ Pickle_file = "Test.pickle"). The third parameter is the choice of the Weivlet family (example: ST = "DB30"). It should be noted that the output parameters of an instance of the class are assigned to a local variable class (example: self.path_directory = Path_directory)

Block №3 - An empty variable, such as a list, as well as forming a variable Files_into_directory, which contains the names of the files of the specified directory in the variable Self.path_directory.

Block №4 - the repeated path to the file in the specified directory in the instance of the class is formed.

Block №5 - reading data from an audio file. The calculation of the maximum level of decomposition is performed to calculate the approximating part. After that, on the basis of the received data, the transformation is performed to obtain the approximating part, followed by the calculation of the length of the received data. I note that this is necessary in order to calculate the required length for the entire sample, since the training of the neural network requires a fixed value of the entire matrix.

Block №6 - the minimum value is detected, as well as the creation of a zero matrix with the detected minimum value.

Block №7 - all audio data in wav format is read. A fixed value of the length of the matrix is given, based on the minimum length found among all audio files. The matrix is formed by adding values to the zero matrix specified in block №6.

Block №8 - the zero row of the row of the final matrix is deleted, because it contains zeros.

Block №9 - recording of the received matrix into a pickle format file is performed.

The recognition consists in the fact that we select the approximating parts using wavelet analysis, train the neural network using the matrix of the obtained values, and at the output we get two output neurons[6]. In that case, if it is found that it is English, the first output neuron will acquire the value of one, and the second one will acquire the value of zero. If the neural network decides that it is a Russian language, the second neuron will

acquire the value of one, therefore, the first neuron will acquire the value of zero. The process of weight adjustment is as follows:

$$HNinput_1 = W_{ti} \cdot TI \quad (1)$$

where:
$HNinput_1$ — matrix of input values of the first hidden layer;
W_{ti} — matrix of weights of the input layer TI;
TI — training data matrix[5].

$$HNoutput_1 = f_{activation}(HNinput_1) \quad (2)$$

where:
$HNoutput_1$ — matrix of output values of the first hidden layer;
$f_{activation}(HNinput_1)$ - applying the activation function (sigmoida) over the input data of the first hidden layer $HNinput_1$[5].

I note that the selection of weights is performed randomly according to the normal law of distribution in the range from [- 0.5: 0.5].

$$HNinput_2 = W_{hn1} \cdot HNoutput_1 \quad (3)$$

where:
$HNinput_2$ — matrix of input values of the second hidden layer;
W_{hn1} — matrix of weights of the first hidden layer HN_1;
$HNoutput_1$ — matrix of output values of the first hidden layer.

$$f_{activation} = \frac{1}{1+e^{-x}} \quad (4)$$

where: $f_{activation}$ — activation function (sigmoida).

$$HNoutput_2 = f_{activation}(HNinput_2) \quad (5)$$

where:
$HNoutput_2$ — matrix of output values of the second hidden layer;
$f_{activation}(HNinput_2)$ - applying the activation function (sigmoida) over the input data of the second hidden layer $HNinput_2$

$$HNinput_3 = W_{hn2} \cdot HNoutput_2 \quad (6)$$

where:
$HNinput_3$ — matrix of input values of the third hidden layer;
W_{hn2} — matrix of weights of the first hidden layer HN_2;
$HNoutput_2$ — matrix of output values of the second hidden layer.

$$HNoutput_3 = f_{activation}(HNinput_3) \quad (7)$$

where:

$HNoutput_3$ — matrix of output values of the third hidden layer;

$f_{activation}(HNinput_3)$ - applying the activation function (sigmoida) over the input data of the second hidden layer $HNinput_2$

$$ONinputs = W_{hn3} \cdot HNoutput_3 \quad (8)$$

where:

$ONinputs$ — matrix of input values of the final layer;

W_{hn3} — matrix of weights of the third hidden layer HN_3;

$HNoutput_3$ — matrix of output values of the third hidden layer.

$$ONoutputs = f_{activation}(ONinputs) \quad (9)$$

where:

$ONoutputs$ — matrix of output values of the final layer;

$f_{activation}(ONinputs)$ - applying the activation function (sigmoida) over the input values of the final layer $ONinputs$.

$$d_{output} = ONetalon - ONoutputs \quad (10)$$

where:

d_{output} — error matrix of the final layer;

$ONetalon$ — reference matrix of values of the final layer;

$ONoutputs$ — the resulting matrix of values of the final layer[5].

$$d_{hn3} = w_{hn3}.T \cdot d_{output} \quad (11)$$

where:

d_{hn3} — error matrix of the third hidden layer;

$W_{hn3}.T$ — transposed matrix of weights of the third hidden layer HN_3;

d_{output} — error matrix of the final layer.

$$d_{hn2} = w_{hn2}.T \cdot d_{hn3} \quad (12)$$

where:

d_{hn2} — error matrix of the second hidden layer;

$W_{hn2}.T$ — transposed weight matrix of the second hidden layer HN_2;

d_{hn3} — error matrix of the third hidden layer.

$$d_{hn1} = w_{hn1}.T \cdot d_{hn2} \quad (13)$$

where:

d_{hn1} — error matrix of the first hidden layer;

$W_{hn1}.T$ — transposed weight matrix of the first hidden layer HN_1;

d_{hn2} — error matrix of the second hidden layer;

$$F'_a = F_a \cdot (1 - F_a) \tag{14}$$

where:
F'_a — derivative activation function (sigmoida);
F_a — layer output values[5].

$$W'_{ti} = W_{ti} + F'_a(HNoutput_1) \cdot TI.T \cdot a \tag{15}$$

where:
W'_{ti} — updated matrix of weights of the input layer *TI*;
W_{ti} — matrix of weights of the input layer *TI*;
F'_a — derivative activation function (sigmoida);
TI.T — transposed matrix of input values TI;
α — learning rate[5].

$$W'_{hn1} = W_{hn1} + F'_a(HNoutput_2) \cdot HNoutput_1.T \cdot a \tag{16}$$

where:
W'_{hn1} — updated weight matrix of the first hidden layer *HN1*;
W_{hn1} — matrix of weights of the first hidden layer *HN1*
F'_a — derivative activation function (sigmoida);
$HNoutput_1.T$ — the transposed matrix of the output values of the first hidden layer;
α — learning rate.

$$W'_{hn2} = W_{hn2} + F'_a(HNoutput_3) \cdot HNoutput_2.T \cdot a \tag{17}$$

where:
W'_{hn2} — updated weight matrix of the second hidden layer *HN2*;
W_{hn2} — matrix of weights of the second hidden layer *HN2;*
F'_a — derivative activation function (sigmoida);
$HNoutput_2.T$ — the transposed matrix of the output values of the second hidden layer;
α — learning rate.

$$W'_{hn3} = W_{hn3} + F'_a(ONouputs) \cdot HNoutput_3.T \cdot a \tag{18}$$

where:
W'_{hn3} — updated weight matrix of the third hidden layer *HN3*;
W_{hn3} — matrix of weights of the second hidden layer *HN3;*
F'_a — derivative activation function (sigmoida);
$HNoutput_3.T$ — the transposed matrix of the output values of the third hidden layer;
α — learning rate.

IV. RESULTS

Five directories filled with samples of the Russian and English languages were created to check the functionalityspeech recognition.

Each directory counted 5 samples of each language. In the table 1 shows the results of the neural network of two directories.

Table №1 – The results of the neural network

eng	0.99979599	0.00020401
eng	0.99975415	0.00024585
eng	0.99976293	0.00023707
eng	0.99995951	4.04938865e-05
eng	0.99808374	0.00191626
rus	1.15805388e-05	0.99998842
rus	3.49035619e-05	0.9999651
rus	5.7168482e-06	0.99999428
rus	1.18034111e-05	0.9999882
rus	1.60860732e-05	0.99998391
eng	0.99979636	0.00020364
eng	0.99979615	0.00020385
eng	0.99972935	0.00027065
eng	0.9997959	0.0002041
eng	0.99979615	0.00020385
rus	5.52566322e-06	0.99999447
rus	1.11128233e-05	0.99998889
rus	1.19122191e-05	0.99998809
rus	5.70699932e-05	0.99994293
rus	1.6217521e-05	0.99998378
eng	0.99979622	0.00020378
eng	0.99979624	0.00020376
eng	0.99979624	0.00020376
eng	0.99978415	0.00021585
eng	0.99838725	0.00161275
rus	2.47732505e-05	0.99997523
rus	0.00030373	0.99969627

rus	0.00013856	0.99986144
rus	8.52489696e-06	0.99999148
rus	4.531384e-05	0.99995469
eng	0.99979634	0.00020366
eng	0.99979628	0.00020372
eng	0.99979456	0.00020544
eng	0.99979628	0.00020372

V. CONCLUSIONS

It can be concluded that out of 25 samples, 23 were correctly recognized, which is 92%. The recognition speed of 1 directory with 10 samples is 0.0269. It has been found that the optimal level of decomposition (decomposition level) is dl = 8 for the performance of the given task. When dl > 8, the quality of learning the neural network significantly deteriorates and drops to 85%. In the case of dl < 8, the performance remains the same as when dl = 8, but the amount of input data increases, causing the recognition speed to decrease.

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MACHINE LEARNING MODELS AND TECHNOLOGY FOR CLASSIFICATION OF FOREST ON SATELLITE DATA

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Abstract. *The project deals with the problem of semantic segmentation of satellite imagery to deliver forest type map with high resolution. To solve the problem, we propose 4 different variations of machine learning models. Two of them are based on Random Forest and other two - on convolutional neural network – U-Net. As an input we use 2 images of Sentinel-2 (one for summer and one for winter, 4 spectral bands from each). As an output (labels) we use the Copernicus Forest Type dataset for 2018 year. Our models showed promising results on validation data. Of all models the one based on U-Net ended up being the most efficient in forest classification. After comparing the results, we used the best model to create and compare forest maps of northern part of Kyiv region of 2018 and 2022 years. The experiment confirmed the robustness of the model and it`s scalability. The developed models have been implemented in the cloud platform specialized on satellite data - CREODIAS. The created map can provide valuable data for foresters, biologists, or other researchers to make decisions about forest management and conservation, as well as to ensure that Europe's forests are managed in an ecologically sustainable way.*

Keywords: *machine learning, forest type classification, Sentinel-2, Random Forest, convolutional neural network, U-Net*

I. INTRODUCTION

Forests are an essential ecosystem for our planet. They are home to most animals and birds, and more than 1.6 billion people depend on them for their livelihoods. Forests are the lungs of our planet, providing hydrological regulation, erosion prevention, and carbon storage. The value of environmental services provided by forests is more than 100 trillion euros per year, which exceeds the entire world's GDP.

Therefore, the inventory and monitoring of the state of forests are crucial, especially concerning climate change, when the risks of emergencies such as forest fires, droughts, and windstorms increase significantly. Monitoring the health of forests in Europe is the focus of Horizon Europe's SWIFTT project (https://swiftt.eu/), which has just started and will continue for three years. A central task of this project is to build a detailed map of European forests based on satellite data. Since this task requires object recognition based on a large amount of satellite data, it must be solved using machine learning models. This project is devoted to developing such a model and information technology for forming a detailed map of forests in Europe with machine learning. Considering the large amount of data that needs to be processed, these models and information technologies are reasonable

to implement in a cloud environment. We selected the CREODIAS (https://creodias.eu/) cloud platform, which is being developed under the support of the European Space Agency and provides direct access to the Copernicus satellite data repository.

Creating a technology for mapping the forest with high accuracy is important because it can help with better understanding the characteristics of European forests and the ways in which they are changing over time.

Although in this research, we solve the problem of classification for a relatively small area, our model could be scaled to obtain a map of forests for the whole of Europe. It is important because the current maps are outdated, and information on the typical composition of forests needs to be updated. It may be needed by foresters, biologists, or other researchers of the forest, who care about its health and also record the consequences of the events that happened. Available products (maps) contain a small number of classes or have coarse resolution, and therefore do not give us a complete picture of the state of the forest. And accordingly, obtaining the necessary high-resolution data is quite difficult, time-consuming, expensive, and resource-intensive.

II. RELATED WORK

2.1. Review of existing methodology for land cover/forest classification based on satellite data

With the launch of the Copernicus program and availability of a large amount of free satellite data, a lot of scientific publications and ready to use products have been developed. During the last 20 years the most popular techniques were Random Forest [1]1, SVM [2], MLP [3]. In particular, scientists from Boston University [4] already in 2002 described neural network algorithms [5], which has been used to obtain a land cover classification map for the whole world based on MODIS data with a spatial resolution of 1 km. With the launch of the Landsat satellite, GLC2000 global land cover maps with a spatial resolution of 30 meters began to appear, which was a significant breakthrough and advance in the field of remote sensing of the earth [6], [7]. Given the higher resolution and the corresponding increase in the volume of data that needed to be processed for the land cover classification at world level, experts used "light" algorithms such as Random Forest [1] and Support Vector Machine [2].

Recently, deep learning algorithms became increasingly popular for land cover classification due to their ability to learn complex patterns from large datasets [8]. Such models are capable of extracting features from satellite imagery that are not easily distinguishable by traditional methods. This makes them particularly useful for tasks such as forest classification, where features such as texture, shape, and spectral signatures can be used to classify different land cover types. Additionally, deep learning algorithms are capable of generalizing well to unseen data, which makes them highly suitable for use in this domain. There are a number of deep learning algorithms that can be used for classification, including convolutional neural networks (CNNs), recurrent neural networks (RNNs), and generative adversarial networks (GANs). Of these, CNNs are the most widely used and are known for their performance in image classification tasks and especially U-Net is the most suitable architecture for semantic segmentation [9].

2.2. Review of existing forest type classification products

Worldwide land cover mapping (WorldCover 2020&2021)

The ESA WorldCover provides the first global land cover products for 2020 [10] and 2021 [11] at 10 m resolution, developed and validated in near-real time based on Sentinel-1 and Sentinel-2 data.

The discrete classification map provides 11 classes (Fig. 1) and is defined using the Land Cover Classification System (LCCS) developed by the United Nations (UN) Food and Agriculture Organization (FAO).

The WorldCover map validation was carried out by Wageningen University, and showed that the overall accuracy of the WorldCover product with 11 classes is 74.4% on a global scale, with accuracy levels by continent ranging from 68 to 81% [12].

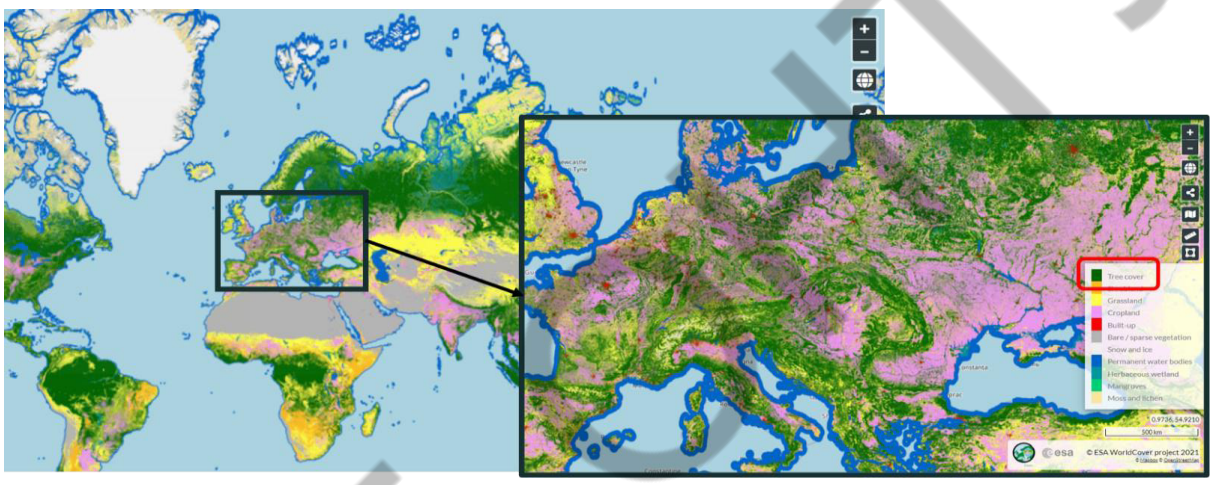


Fig. 1 The WorldCover land cover product at 10 m resolution for 2020/2021 based on both Sentinel-1 and Sentinel-2 data

The ESA WorldCover products are delivered in 3x3 degree tiles as Cloud Optimized GeoTIFFs (COGs) in EPSG:4326 projection (geographic latitude/longitude CRS). There are 2651 tiles, each tile contains 2 data layers:

- Map: Land cover map with 11 classes, a total of approximately 117 GB.
- InputQuality: Three band GeoTIFF providing three per pixel quality indicators of the Sentinel-1 and Sentinel-2 input data.

Global Forest Change 2000–2021

The Global Land Analysis and Discovery (GLAD) laboratory at the University of Maryland, in partnership with Global Forest Watch (GFW), provides annually updated global-scale forest loss data, derived using Landsat time-series imagery with spatial resolution 30 meters. These data are a relative indicator of spatiotemporal trends in forest loss dynamics globally.

Results from time-series analysis of Landsat images in characterizing global forest extent and change from 2000 through 2021 [13].

CGLS-LC100 - Forest cover (2015 - 2019)

The Dynamic Land Cover map at 100 m resolution (CGLS-LC100) is a new product in the portfolio of the CGLS and delivers a global land cover map based on PROBA-V 100 m satellite data for 2015-2019 (Fig. 2, [14]). In this product, those pixels where forest cover is above 30% are considered forest cover. The accuracy of this product reaches 80% for all years.

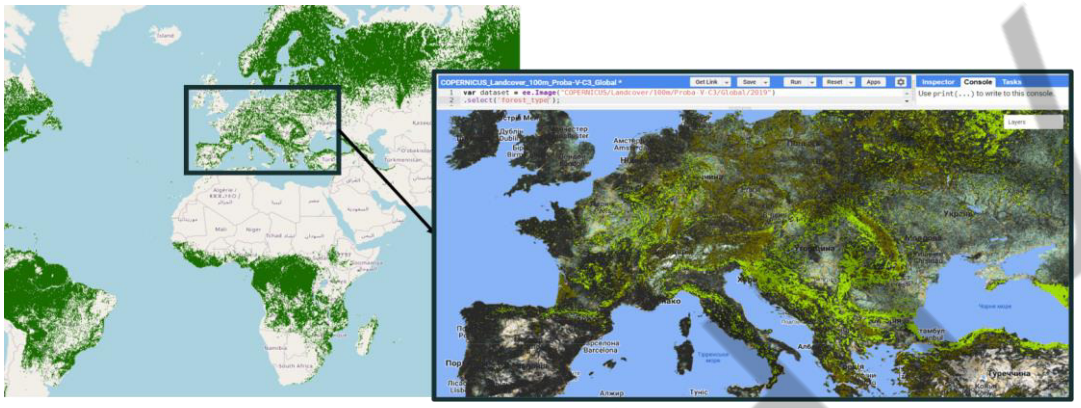


Fig. 2 Forest cover (FAO) based on PROBA-V 100 m data

Forest Type 2018

Data is provided by Copernicus Land Monitoring Service as 10 meter rasters in 100 x 100 km tiles grouped according to the EEA39 countries, as well as a full EEA39 mosaic. The Forest Type 2018 status layer at 10m spatial resolution is mainly based on the primary status layer Dominant Leaf Type 2018, which was produced by a hierarchical spatio-temporal classification of time features derived from Sentinel-2A+B time series (Level-2A data) using a Random Forest (RF) classifier with 500 trees. The Forest Type raster product provides a forest classification with 3 thematic classes (all non-forest areas / broadleaved forest / coniferous forest) with accuracy minimum 90% user's and producer's for both forest classes (Fig. 3). Forest Type map for 2018 does not cover Ukraine.

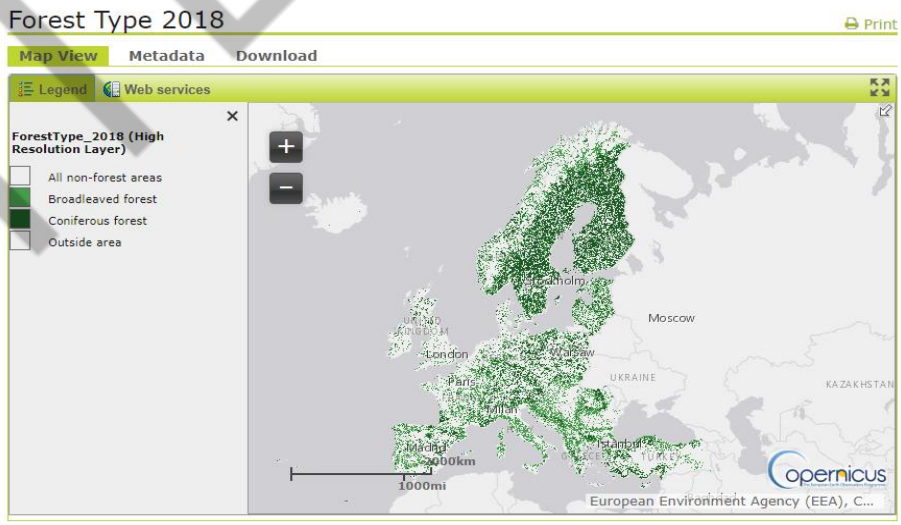


Fig. 3 Forest Type 2018

Forest Map of Europe

Two different earth-observation products [15], [16] have been combined with statistical data to produce a new pan-European forest map at 1 km resolution that corresponds to the official forest inventory statistics at national and/or regional level.

European forest disturbance maps (1986-2020)

The annual forest disturbances across 35 European countries derived from Landsat satellite data. The disturbance maps currently cover the time period 1986-2020 and are accompanied by a map of disturbance severity (for the moment only until 2016) and a forest mask. The methodological details are explained in [17].

As a result of the analysis of the existing sources of European forest classification maps, the six most popular resources were selected (Table 1). The use of the given resources is not appropriate due to their irrelevance as well as the lack of division into the necessary types. So, for example, WorldCover offers 10 m spatial resolution data for 2020-2021 years, which is relatively new, but the forest is represented only in the form of tree cover. At the same time, Forest Type 2018 provides data highlighting the necessary categories of forests: deciduous, coniferous, and non-forest, but they are available only for 2018 at the latest, which indicates their obsolescence. Instead, these products can be used for labeling the training and test datasets.

Table 1 Available free European forest classification maps

Product name	Years	Spatial resolution	Accuracy	Forest type	Link
WorldCover	2020, 2021	10 m	68 – 81%	No	link
Global Forest Change	2000 - 2021	30 m		No	link
CGLS-LC100	2015 - 2019	100 m	80%	Yes	link
Forest Type 2018	2018	10 m	90%	Yes	link
Forest Map of Europe		1000 m		No	link
European forest disturbance maps	1986-2020	30 m	87.6±0.5 %	No	link

III. OBJECT, SUBJECT AND METHODS OF RESEARCH

3.1. Description of the pilot area

Germany was chosen as the main area of interest, on which territory we have chosen 5 test study areas (4 training and 1 validation) (Table 2). Experiment has been done on 2018 data, as well as there is a satellite product with the Forest Type 2018 map of forests in Europe, which could be used for validation. Each test study area is covered by 1 scene with the size 10000x10000 pixels (100x100 km) (Fig. 4).

Table 2 Class distribution on each study area

Classes\Zones	1	2	3	4	5	Total
Non-Forest	73.38%	75.29%	63.46%	69.88%	66.53%	69.71%
Broadleaved	14.39%	17.14%	8.67%	10.90%	19.14%	14.05%
Coniferous	12.23%	7.57%	27.87%	19.22%	14.33%	16.24%

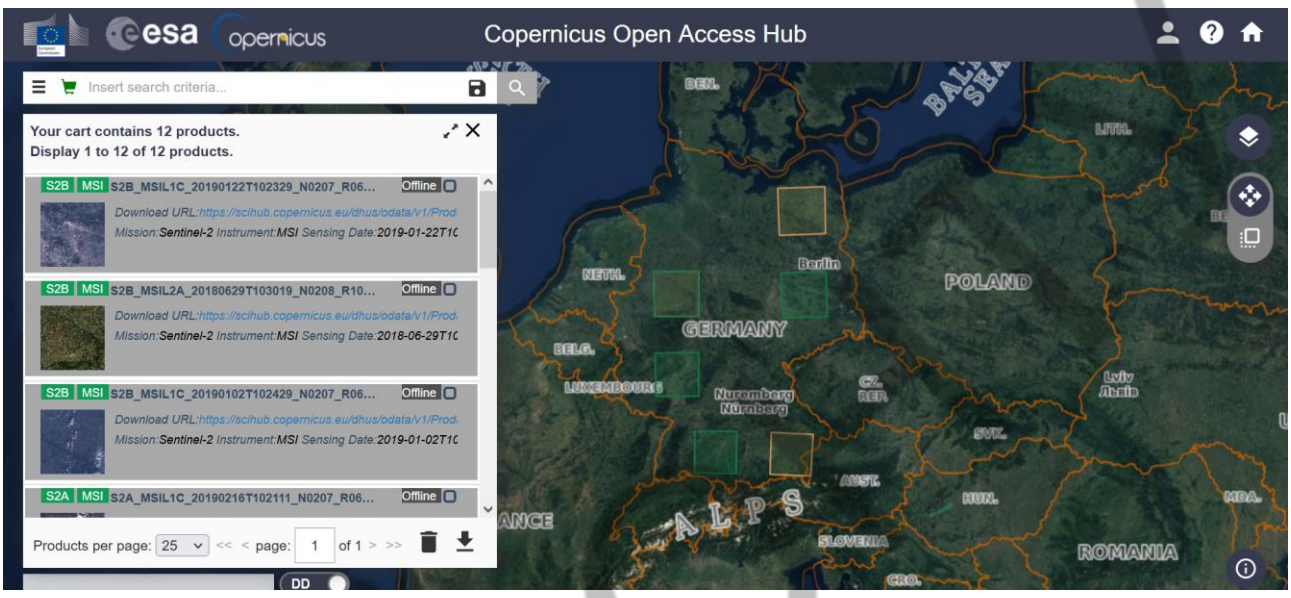


Fig. 4 Location of 5 test study areas in Germany

3.2. Description of data used

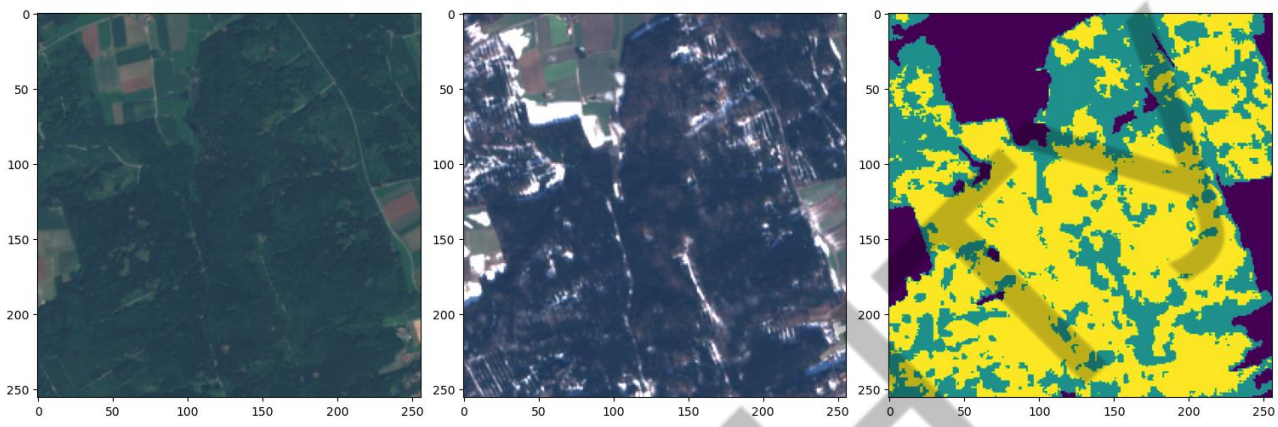
To deliver high resolution map of forest types we utilize free of charge data of European satellite Sentinel-2 from Copernicus program, in particular Sentinel-2 mission. It contains 2 optical satellites observing each point on the Earth every 12 days [18]. Sentinel-2 is a wide-swath, high-resolution, multi-spectral imaging mission, supporting Copernicus Land Monitoring studies, including the monitoring of vegetation, soil and water cover, as well as observation of inland waterways and coastal areas. The Sentinel-2 Multispectral Instrument (MSI) samples 13 spectral bands: four bands at 10 meters, six bands at 20 meters and three bands at 60 meters spatial resolution. The acquired data, mission coverage and high revisit frequency provides for the generation of geoinformation at local, regional, national and international scales.

In our study we work with 10-meter spatial resolution bands. Input data for our models are 4 bands (B02, B03, B04, B08) of Sentinel-2 L1C satellite images from winter and summer periods (total of 8 bands):

- B02 - blue spectral band (center 490 nm)
- B03 - green spectral band (center 560 nm)
- B04 - red spectral band (center 665 nm)
- B08 - near infrared (NIR) spectral band (center 842 nm)

For training, labels were taken from the Copernicus Forest Type 2018 dataset. More information there is in product overview part. An example of input and output (labeled) data is shown on the Fig. 5**Ошибка! Источник ссылки не найден.**.

We deal with a problem of semantic segmentation, that's why it is reasonable to use a convolutional network for classification. For comparison we will use the well-known Random Forest classifier. Let's describe the architecture of each model.



a) b) c)

Fig. 5 Examples of 3 band composite of two 4-band input images: for summer - a) and for winter b) and labeled image (c) used as an output of the model. The colors represent appropriate results of classification: purple - non-forest area, green - broadleaved forest, yellow - coniferous forest.

3.3. Random Forest model

One of popular machine learning algorithms is Random Forest (RF) [19]. The idea of the algorithm is training multiple decision trees and then using them to clarify the output of the model. The result is chosen by majority of decision trees choices [20]. What is a decision tree? The idea is very simple. You can imagine one as a tree graph, each node of which is asking a question. For example - "is input number divided by 5?", if the answer is yes- input goes, for example, to the left neighbor node, else- to the right. In the process of training decision trees grow in depth and gain more accuracy. However, overfitting on one decision tree is very common, that's why we use Random Forest.

3.4. Convolutional neural network

Another modern paradigm of machine learning is Convolutional Neural Networks (CNN). For this project we used the U-net model with a Resnet34 encoder. This is a convolutional neural network, which is most suitable for semantic segmentation problems in machine learning (ML) [21]. Model consists of two parts: encoder and decoder. On this particular model encoder is a backbone of Resnet34 (Fig. 6).

U-Net is a type of convolutional neural network that uses an encoder-decoder architecture to segment images into regions of interest. Specifically, U-Net can be used to identify trees and other objects in aerial images. ResNet34 is a deep learning model based on the ResNet architecture. It consists of 34 layers and is designed for object classification.

When used for forest classification, ResNet34 can accurately identify different species of trees and other objects in aerial images. Additionally, ResNet34 can be used to detect different types of damage in trees, such as insect infestations or disease.

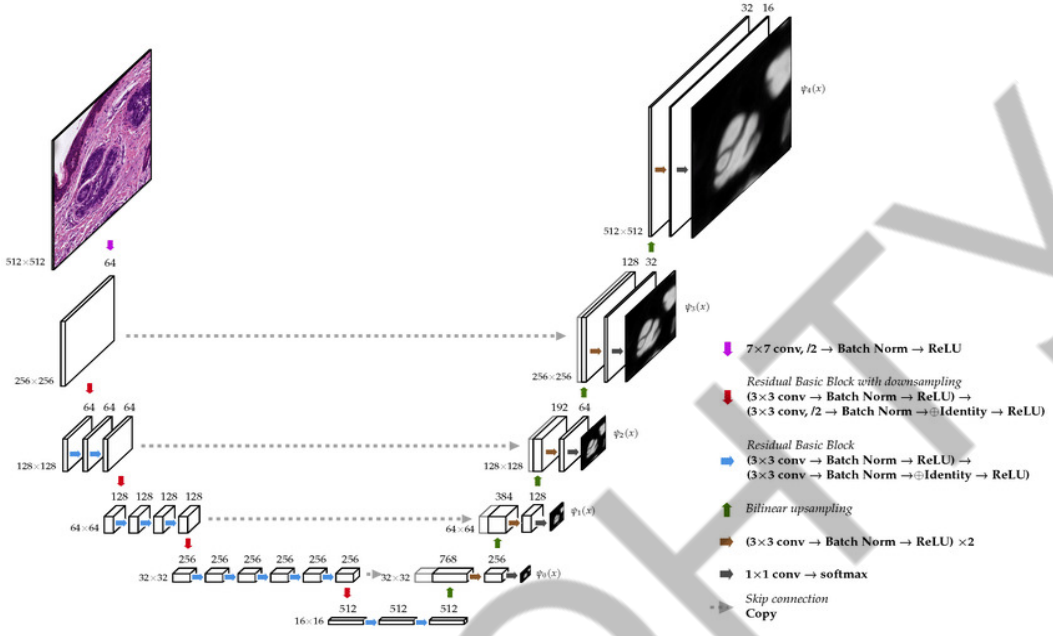
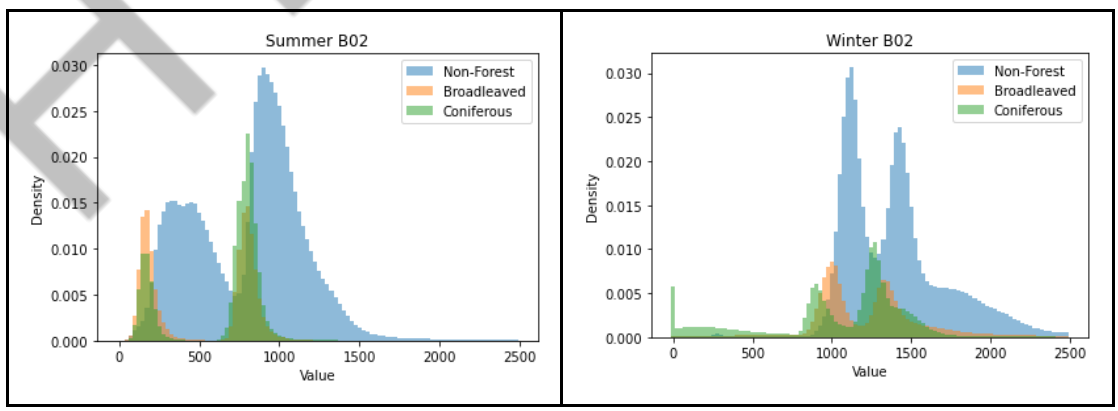


Fig. 6 U-net model with a Resnet34 encoder [21]

IV. OUR RESULTS

4.1. Preliminary data analysis

A preliminary analysis of our dataset was performed. The histogram of the distribution of component values for each class for winter and for summer imagery is shown in Fig. 7. The results of preliminary data analysis showed that differing broadleaf and coniferous can be quite difficult task for most bands (except for summer B08), therefore we should expect confusion matrix to show model confusing these two classes much more often than, any other pair.



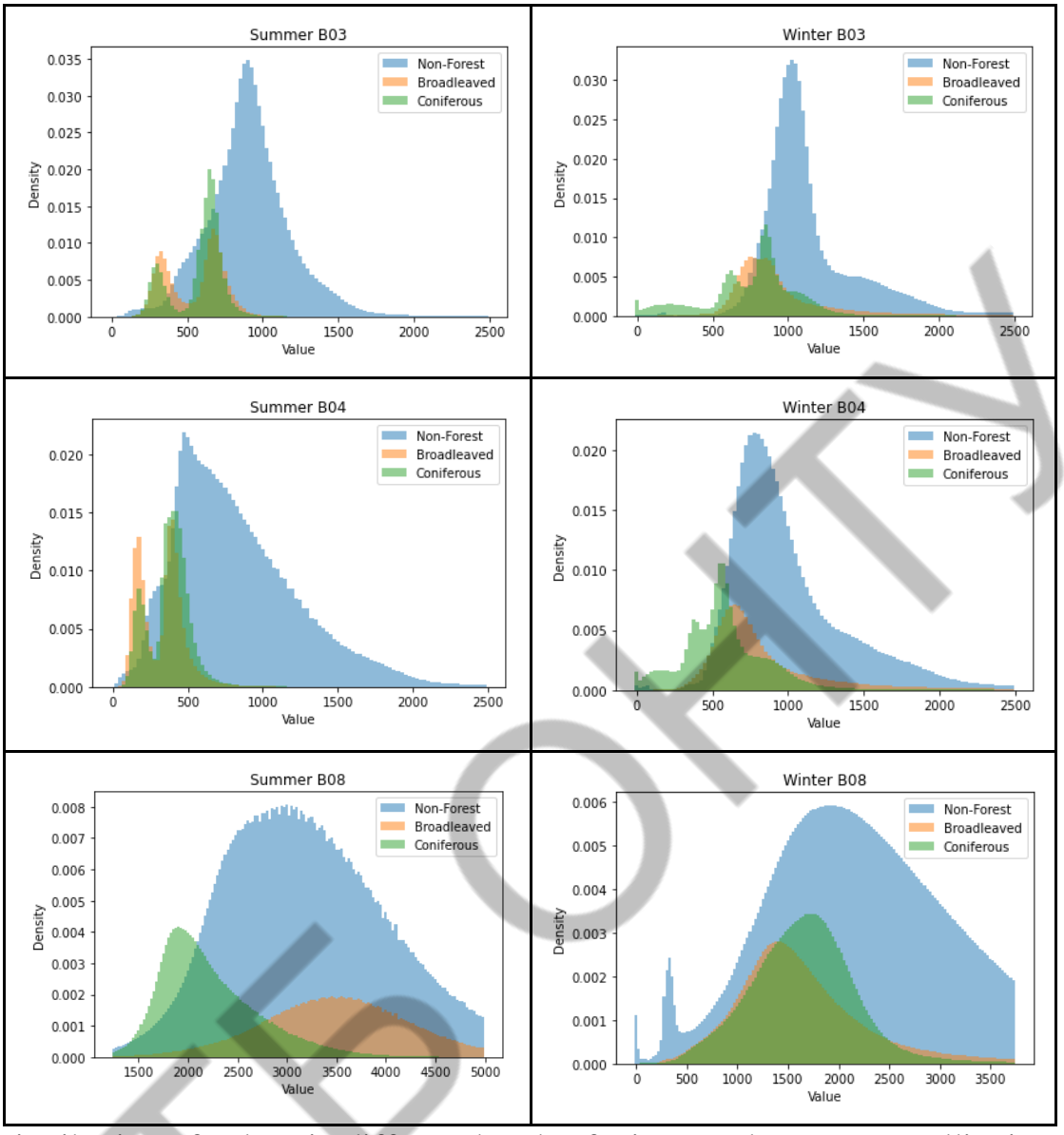


Fig. 7 Distribution of values in different bands of winter and summer satellite image for different classes

4.2. Proposed classification models and experiment description

First part of our experiment consists of experimenting with a few simple classifiers based on Random Forest (RF). Our model uses the following parameters: maximum depth - 125, maximum samples - 0.005, number of estimators per group - 2.

RF also has several pitfalls, which are related to the fact that this method is not incremental, and therefore requires to transfer all the data for training at once, which is impossible for a large sample. As a result, the training data had to be grouped and for each of the obtained groups we should build it's own estimators. This, in turn, creates a situation when the model is trained quickly, but with an increase in the number of groups, the time for prediction increases linearly. Also, for groups not created in a special way, such an approach can lead to decreasing the accuracy, since each individual tree does not contain

all the information about the class. Due to the simplicity of RF, the only difference between the models is what data we will transmit to them.

The first model (let's call it RF1) takes our original data as input. That is, information about the brightness of the corresponding pixel for each of the channels. A total of 8 channels per pixel.

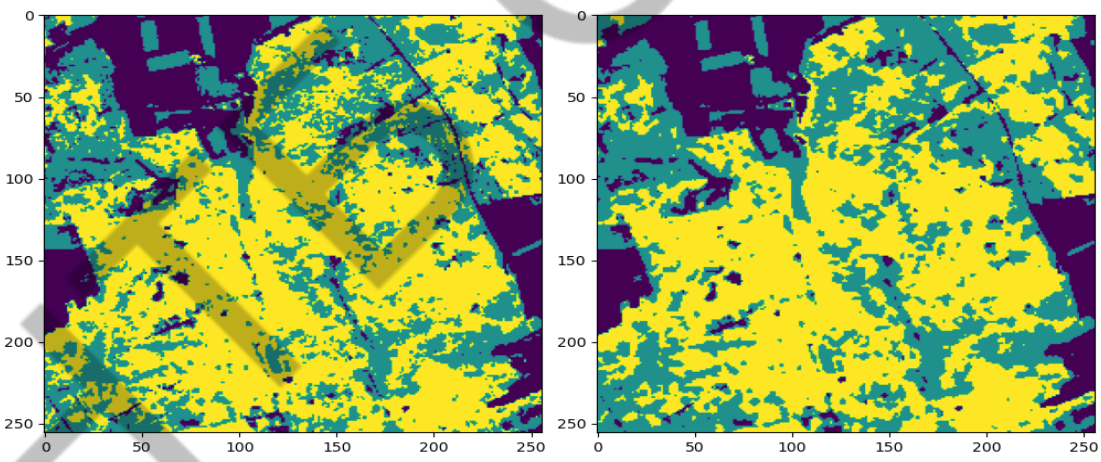
The second model (RF2) also receives information about the luminance of the corresponding pixel of all channels after using an averaging filter with a 3 by 3 window and also after using a Laplace filter [22] of the same size. So, we have 24 channels per pixel in total. Taking into account the size of the training area and the number of estimators per group chosen by us, we have decided each RF to contain 220 estimators.

Second part of our experiment is creating a U-Net model. Our U-Net model (UN1) uses a resnet34 architecture with an encoder depth of 5. For optimization, we improved the model with use of the Adam optimizer [23] and the cross-entropy loss function [24]. As an input, the model accepts a 256 by 256 image containing 8 channels. The model has been trained for 16 epochs.

The second model (UN2) is a modification of UN1, additionally trained with changed weights of the loss function.

The idea of the experiment is to estimate how appropriate is the usage of deep neural networks for such semantic segmentation, or is it better to use less complicated models. Also, we have been considering possible ways of increasing model accuracy.

The results of the classification using each method can be seen on Fig. 8.



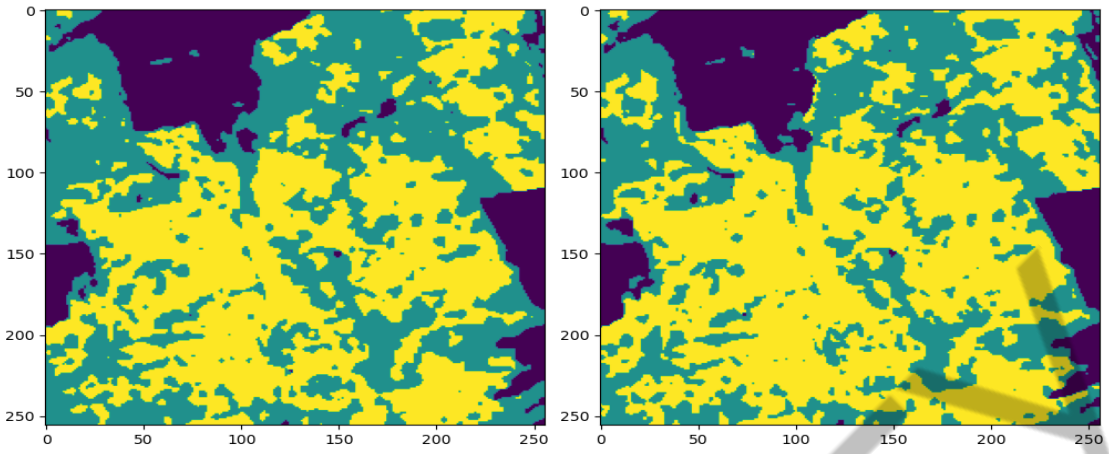


Fig. 8 Results of classification with 4 different models: a (top left) – RF1, b (top right) – RF2, c (bottom left) – UN1, d (bottom right) – UN2

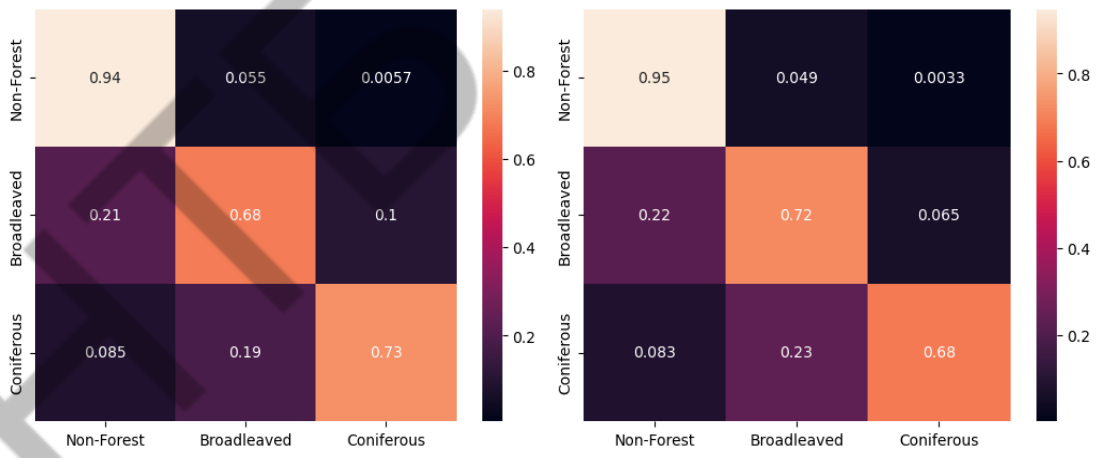
4.3. Discussion of the results

RF1 (Per Pixel Random Forest) -Semantic segmentation with Random Forest

At first look at the obtained results, we can immediately see that this method is good at recognizing small details, such as roads. At the same time, the algorithm has problems recognizing fields that it actively tries to classify as deciduous forests (Fig. 9-a). There are also problems with the accuracy of forest/non-forest recognition.

RF2 (3x3 Filtering Random Forest)

The use of blur and Laplace filters resulted in a reduction of small details, but at the same time the overall accuracy remained almost unchanged (Fig. 9- b).



a) b)

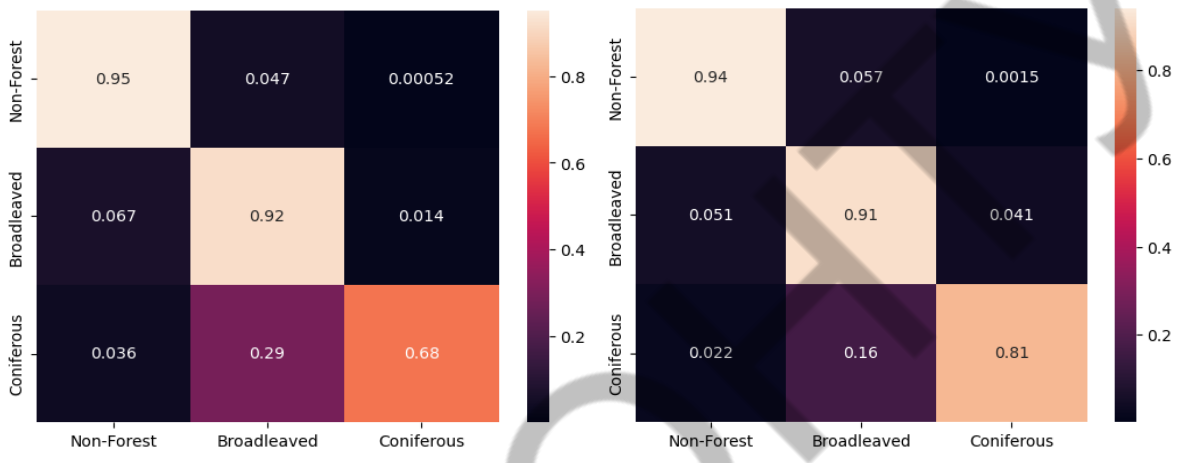
Fig. 9 Normalized confusion matrices of a (left) – RF1, b (right) – RF2

UN1

When we first applied the algorithm and built the confusion matrix, we noticed that the model perfectly recognized the forest (Fig. 10-a). But at the same time, it confuses deciduous and coniferous trees. This corresponds to the results of preliminary data analysis.

UN2

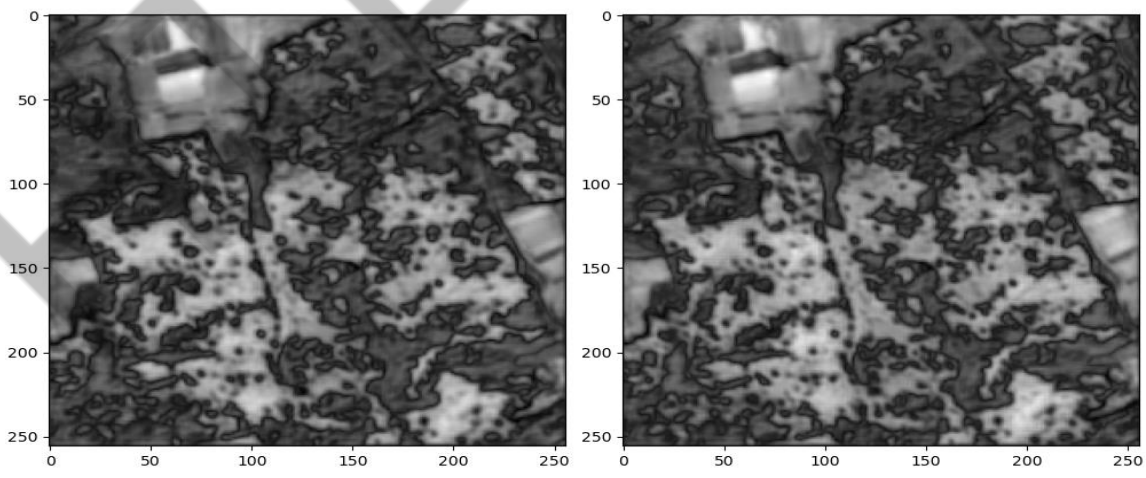
When we analyzed the distribution of our classes on the input data and set the weights to equalize it. After that, the conifer became more recognizable (Fig. 10- b). Although the situation has improved, a significant portion of the coniferous forest is still classified as deciduous forest. Therefore, we looked at how confident the model was in its choice. As can be seen in the image, the model shows a significant degree of confidence when assigning to the Non-Forest and Coniferous classes. However, for deciduous forests, the model is not fully confident.



a) b)

Fig. 10 Normalized confusion matrices of a (left) – UN1, b (right) – UN2

First of all, it tells us that these classes are poorly separated, but it could also mean that the distinction between purely coniferous/deciduous forests may be incorrect and it would be more appropriate to introduce a threshold of confidence, after which we would assign to the exact class, or else say that it is a mixed forest (Fig. 11).

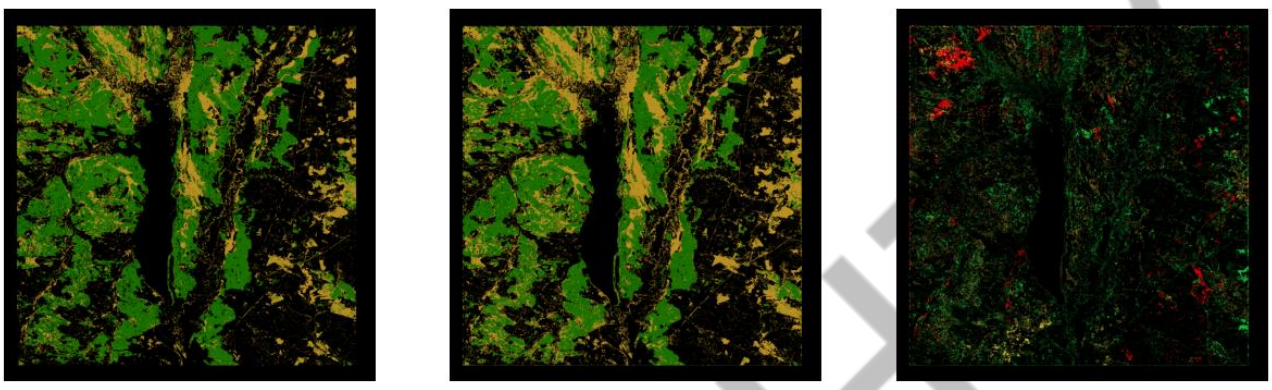


a) b)

Fig. 11 Models' confidence in class selection (whiter is better): a (left) – UN1, b (right) – UN2

4.4. Experiment for Ukraine

Having received the trained model for the territory of Germany, we applied it to the territory of Ukraine, since there is no forest map for the territory of Ukraine and there is no possibility to use it as training. In Fig. 12 we can see the application of our model to look at changes in forest area between 2018 and 2022 years. This territory is located in the north of the Kyiv region near Chernobyl region.



a) b) c)

Fig. 12 Example of classification for Kyiv, Ukraine: a (left) – for 2018, b (middle) – for 2022, c (right) – difference between those years. The colors at (a) and (b) represent appropriate results of classification: black - non-forest area, brown - broadleaved forest, green - coniferous forest. For (c): green - new forest, yellow - forest type mismatch, red - disappeared forest, black - no changes

As we can see form Fig. 12, the model if robust and provides good enough high-resolution map for different geographic area.

4.4. Implementation on the cloud platform

Our machine learning models have been implemented on cloud platform CREODIAS (https://creodias.eu/) [25]. The use of cloud technologies, and especially the CREODIAS platform, is reasonable because it allows us to use powerful resources to achieve our goals. Given that we aim to create a forest map for the whole of Europe, we will need to apply the algorithm to a large amount of data, which may not be efficient using our low capacity. With the use of the cloud, we can rent as many resources as we need. Moreover, CREODIAS offers users its public repository with a large number of satellite images, which is updated daily. Thus, there are no problems with finding data for processing and training the model. And available services of the platform, such as EO Finder and EO Browser, speed up the finding of satellite images according to the necessary parameters.

V. CONCLUSIONS AND FURTHER STEPS

The project deals with problem of classification of forest type using semantic segmentation of satellite images with random forest and U-Net models. We proposed and studied 2 modifications of RF models and 2 modifications of CNN U-Net. During the

development of the corresponding models, it was found that random forest is not the optimal tool for solving such a problem, primarily due to its architectural properties, which do not allow training the model on significant volumes of data. Random forest model showed relatively low overall accuracy. But in general, this method can be used to quickly check whether some transformations on the data will be more effective.

U-Net, in turn, showed significantly better accuracy and higher prediction speed, but, as deep learning suggests, the learning process is measured not in minutes, as in Random Forest, but in tens of hours.

In general, for solving such problems, it is better to give preference to U-Net. Taking into account how similar distributions of values have deciduous and coniferous forests, the question arises whether it is somehow possible to separate them more qualitatively. In addition to using NDVI (Normalized difference vegetation index), it looks interesting to use CIE-LAB color space [26] instead of channels B02, B03, and B04. This transformation allows us to associate our channels with RGB space: R - B04, G - B03, B - B02 (or, since vegetation is better distinguished in the red part of the spectrum: R - B03, G - B04, B - B02).

Along with this, optical satellite imagery suffers from the problem of shadows (from mountains, from buildings, etc.), which leads us to think that it would be good to separate the color part of the image from the intensity, for which the LAB and HSV color spaces are usually used.

The LAB model is representative of a homogeneous space in which the distance uniquely indicates the magnitude of the difference between colors. It is worth noting that LAB provides the highest degree of separation of luminance and color information compared to other color spaces.

As a result of the project we have delivered a new forest map for study area in Europe, differentiating between coniferous, deciduous, and mixed forests, which will help to better understand the various types of forests in Europe. Our experiments on utilizing the pretrained models for the territory of Ukraine show proposed approach to be robust and applicable for semantic segmentation of satellite imagery in different geospatial locations. Thus, it could be used for delivery of actual forest map for Europe and also for Ukraine.

The developed model and forest type map be used in Horizon Europe SWIFTT project (https://swiftt.eu/) as a basemap to monitor forest health, as it will help to identify areas of particular concern, such as deforestation, overgrazing, and forest fires. Finally, our technology will provide valuable data for policymakers, ecologists, and conservationists. This information can be used to make decisions about forest management and conservation, as well as to ensure that Europe's forests are managed in an ecologically sustainable way.

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EFFICIENT AUTOMATIC CONTROL OF THE ENERGY-SAVING PROCESS OF DEALCOHOLYZATION OF WINE IN THE FLOW IN A THERMOELECTRIC HEAT PUMP INSTALLATION

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Abstract. *The work is devoted to development systems of efficient automatic control of the energy-saving process of dealcoholization of wine in the flow in a plant with a thermoelectric heat pump. For this, the technological process (TP) was studied, an effective regulation of the TP management was found, a structural diagram of the process was drawn up as an OK, dynamic and quasi-static characteristics were studied and obtained from a simulation model in the Matlab environment Simul and nk, development and parametric optimization of control algorithms were carried out.*

Key words: *Dealcoholization, azeotrope point, thermoelectric converter, evaporation, condensation, heat and mass transfer, automatic control, parametric optimization.*

I. INTRODUCTION

Dealcoholization is one of the technological processes of wine production. The separation of alcohol from the wine material requires heating the product to the boiling point of alcohol and further heating to evaporate the alcohol. When the pressure is reduced to 80 mbar, the boiling point of alcohol is 27 ℃. This temperature is called the "azeotrope point", below which no water evaporates from the wine, but only alcohols and ethers evaporate. When working in this mode, the energy consumption for heating raw materials, due to the low boiling point, and for the liquid-vapor phase transition, due to the evaporation of only alcohols and ethers, is significantly reduced.

Another way to reduce energy costs and reduce the level of thermal "energy waste" in the technological processes of the food industry is the use of thermoelectric heat pumps, which in this case heat the wine material and evaporate alcohols and cool and condense alcohol vapors. But their introduction increases the number of interconnections in the OC, which definitely complicates the management of the TP.

The work is dedicated to solving this problem. In the course of which, a process simulation model was implemented in the Matlab simulation environment In Simulink , the static and dynamic properties of the main conversion channels were studied on the process simulation model, the process control algorithms were developed and the behavior of the control system was simulated.

II. LITERATURE ANALYSIS

There are various methods of automatic control of the dealcoholization process, which differ in technological schemes, the number of adjustable parameters and control methods.

A method of automatic process control is known the removal of alcohol from the drinking liquid by means of vacuum extraction , which includes measuring and regulating the flow of wine in contact with the distribution surface, measuring and regulating the internal pressure of the vessel at the level of 16 to 29 inches of mercury. and measuring and adjusting the temperature of the wine in contact with the distribution surface between 30° C and 60° C [see application for invention, USA No.: 20130243922 A1. Removal of alcohol from potable liquid using 50 vacuum extraction / Judd B. Lynn, Kelli Lynn Fuller. Publ. 19.09.2013. fig. 3] [1] .

The disadvantage of this method of automatic control is high energy consumption for heating raw materials, due to high boiling point, and for liquid-vapor phase transition, due to evaporation of not only alcohols and ethers, but also water.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The process of dealcoholization of wine is a complex heat-mass exchange process of evaporation of alcohols from the wine material. To reduce the boiling temperature, with the aim of significantly reducing energy consumption, as well as reducing the degradation of the taste and useful properties of wine, the evaporation of alcohols is carried out at low pressure. This process is called vacuum dealcoholization. When the pressure is reduced to 80 mbar, the boiling point of alcohol is 27 ℃. This boiling point of the water-alcohol solution is called the "azeotrope point", below which no water evaporates from the wine, but only alcohols and ethers evaporate.

The hardware and technological scheme of the process of dealcoholization of wine in the flow in the installation with a thermoelectric heat pump is shown in Fig. 1 .

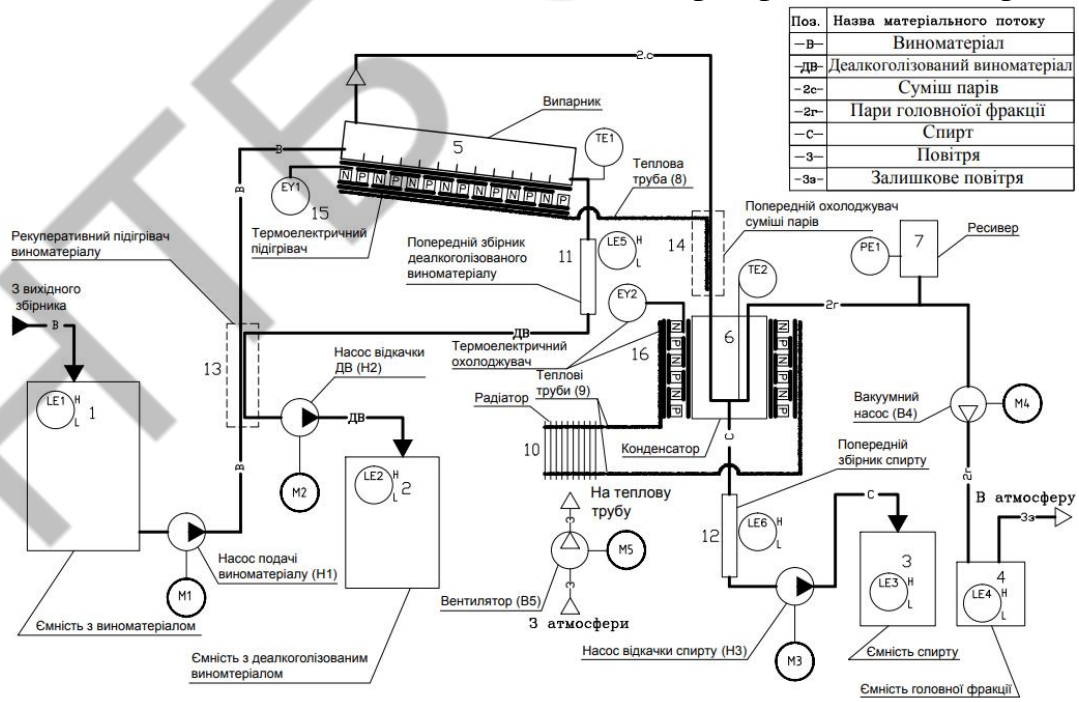


Fig. 1 – Equipment and technological scheme of the process of dealcoholization of wine in the flow in the installation with a thermoelectric heat pump

Air is pumped out of the system by a H4 vacuum peristaltic pump to a pressure of 68mBar (Measured by the PE1 sensor). From the receiving container 1, the peristaltic wine material supply pump H1 through the recuperative wine material heater 13 supplies the wine material to the evaporator 5. In it, the heat flow from the "hot side" of the thermoelectric heater 15 heats the wine to a temperature of 28 **º C** (Measured by the TE1 sensor) and the alcohols evaporate. The dealcoholized wine material (DV) enters the preliminary collection of DV 11, from where, upon reaching the upper level (Measured by the sensor L E5), the DV pump H2 is pumped through the recuperative wine material heater 13 into the DV container 2. The mixture of vapors from the evaporator 5 under the influence of the pressure drop in the steam pipeline cooler, the vapor mixture enters the condenser. In it, they are cooled by the cold from the "cold side" of the thermoelectric cooler 16 to a temperature of + 19°C (Measured by the TE2 sensor). The alcohol is condensed, collected in the preliminary alcohol collector 12, and when the upper level is reached (Measured by the sensor L E6), it is pumped by the alcohol pumping pump H3 into the alcohol tank 3. The vapors of the main fraction are pumped out by the vacuum peristaltic pump H4 into the tank of the main fraction 4, where they are condensed under atmospheric pressure. Residual air is removed to the atmosphere.

To carry out the process of vacuum dealcoholization of wine, it is necessary to maintain the specified pressure level in the vacuum system and to supply heat to the evaporator 5 and remove excess heat from the condenser 6, maintaining the specified pressure in them. Several thermoelectric modules on Peltier elements are used as thermoelectric heater 15 and thermoelectric cooler 16 . The "hot side" of the thermoelectric heater heats the evaporator 5, the "cold side" connected to the heat pipe 8 cools the pre-cooler of the vapor mixture 14. The "cold side" of the thermoelectric cooler cools the condenser 6, and the heat flow from the "hot side" is removed with the help of heat pipes 9 to the radiator 10, from which the heat is blown by the B5 fan.

An intermediate receiver 7 is installed between the condenser and the vacuum pump, the purpose of which is to stabilize sharp pressure fluctuations in the vacuum system.

Level measurements in the wine, DV, alcohol, and main fraction containers are measured respectively by level sensors LE 1, LE 2, LE 3, and LE 4. Peltier elements are controlled by current amplifiers EY 1 and EY 2.

The regulations for conducting the technological process of vacuum dealcoholization of wine are given in Table 1.

Table 1 - Table of regulations

Name of parameters	Marking	Unit of measurement	Nominal value of the parameter	Permissible deviations from face value		
				Long ($t\to\infty$)	Short-term ($0<t<<\infty$)	
				size	size	time, sec
1	2	3	4	5	6	7
The temperature of the DW at the outlet of the evaporator	T_{dv}	^{0}C	28	± 0.5	± 1	60
The temperature in the condenser	T_k	^{0}C	19	± 0.5	± 1	60
Pressure in the receiver	P_p	mBar	68	± 2	± 5	60

IV. RESULTS

4.1. Specification of the task of complying with the regulations for managing the technological process of dealcoholization of wine in the flow in a plant with a thermoelectric heat pump, development and implementation of a complex of its models as an object of regulation

Analysis of the technological process of vacuum dealcoholization of wine in the stream as OK allows us to identify three main regulation tasks:

1. Stabilization of pressure in the receiver;
2. Stabilization of the DV temperature at the outlet of the evaporator;
3. Temperature stabilization in the condenser.

The structural diagram of the technological process of dealcoholization of wine in the flow in the installation with a thermoelectric heat pump as the OK of the object is shown on Figure 2.

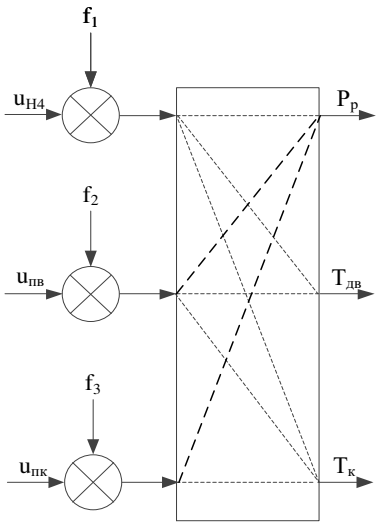


Fig. 2 – Structural diagram of the object of regulation

In fig. 2 the following designations are given:

Regulated variables:

P_p – pressure in the receiver;

T_{dv} – the temperature of DW at the outlet of the evaporator ;

T_k - the temperature in the condenser;

Controlling influences:

U_{n4} – change in the rotation frequency of the vacuum pump motor;

U_{pv} – change in the current of the thermoelectric heater;

U_{pk} - the change in the current of the thermoelectric cooler.

All input actions, except for control actions, are classified as uncontrollable disturbances f_1, f_2, f_3. The deterministic component of these disturbances is additively applied to the control actions, and the stochastic component to the regulated coordinate.

Having performed the decomposition of the technological process on separate structural elements, it can be said that the general mathematical model of the process as OK should have models of heat and mass transfer processes in the evaporator and condenser, thermoelectric converters (TEC) of the evaporator and condenser, the steam pipe from the evaporator to the condenser, heat transfer through a flat wall, pumping out gases from the apparatus and fan with radiator. The figure shows the general structure of the mathematical model of the process of dealcoholization of wine in a stream in a thermoelectric heat pump installation with the main relationships between models of individual elements of the process.

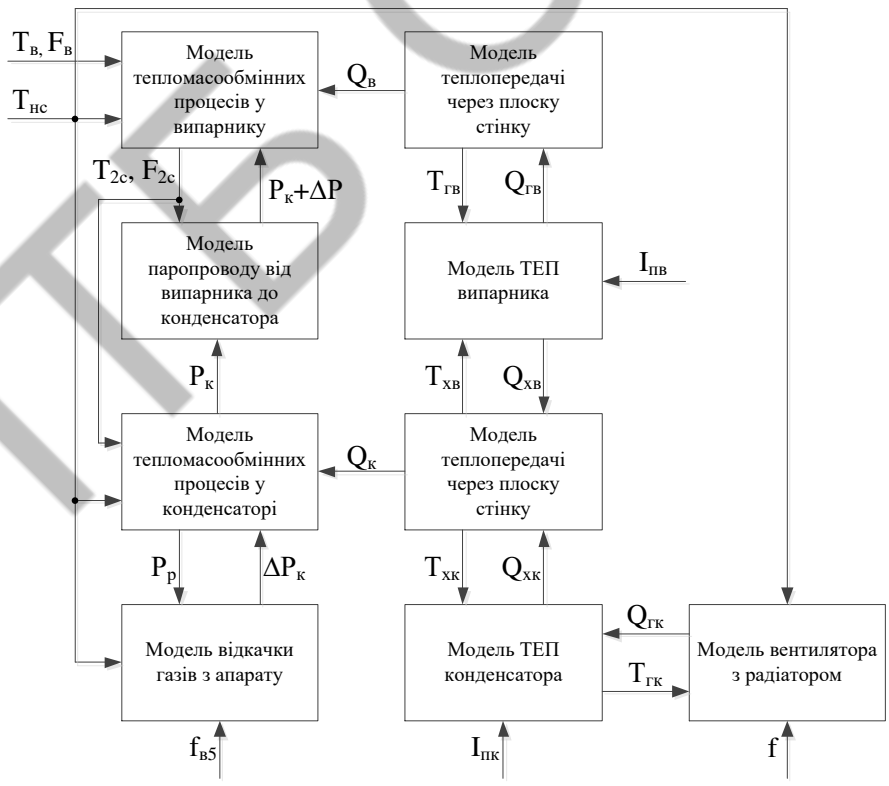


Fig. 3 – Structural diagram of the mathematical model of the process in-flow dealcoholization of wine in a thermoelectric heat pump installation

Where: ΔP - the pressure difference between the evaporator and the condenser;

$F_в$ – consumption of wine material after the recuperative wine material heater;

$T_в$ – the temperature of the wine material after the recuperative heater of the wine material;

$T_{2с}$ – the temperature of the vapor mixture;

$F_{2с}$ – steam mixture consumption;

$P_р$ - pressure in the receiver;

$P_к$ - pressure in the condenser;

$I_{пв}$ – the power supply current of the Peltier thermoelectric elements of the evaporator;

$I_{пк}$ – the supply current of the thermoelectric elements of the Peltier capacitor;

$T_{нс}$ – ambient temperature;

$T_{гв}$ – the temperature of the hot side of the TEC evaporator;

$Q_{гв}$ – heat flow from the hot side of the TEC evaporator;

$T_{хв}$ – the temperature of the cold side of the TEC evaporator;

$Q_{хв}$ – heat flow from the cold side of the TEC evaporator;

$T_{гк}$ – the temperature of the hot side of the TEC condenser;

$Q_{гк}$– heat flow from the hot side of the TEC condenser;

$T_{хк}$ – the temperature of the cold side of the TEC condenser;

$Q_{хк}$ – heat flow from the cold side of the TEC condenser;

$Q_в$ – heat flow to the evaporator;

$Q_к$ – heat flow to the condenser;

f – pump rotation frequency;

$f_{в5}$ – fan rotation frequency.

This model was developed analytically - based on the description of heat and material balance equations, and implemented in the Matlab simulation environment Simulink during the performance of the student research paper "Автоматизація керування процесом вакуумної деалкоголізації вина в потоці" [2].

4.2. Study of the process of dealcoholization of wine in a flow in a plant with a thermoelectric heat pump on its simulation model.

For research of the process of vacuum dealcoholization of wine in the flow as an OK in order to obtain its static and dynamic properties in the main and cross channels of transformations, we will use the simplest structure SAR, the structural diagram of which is presented in Figure 4.

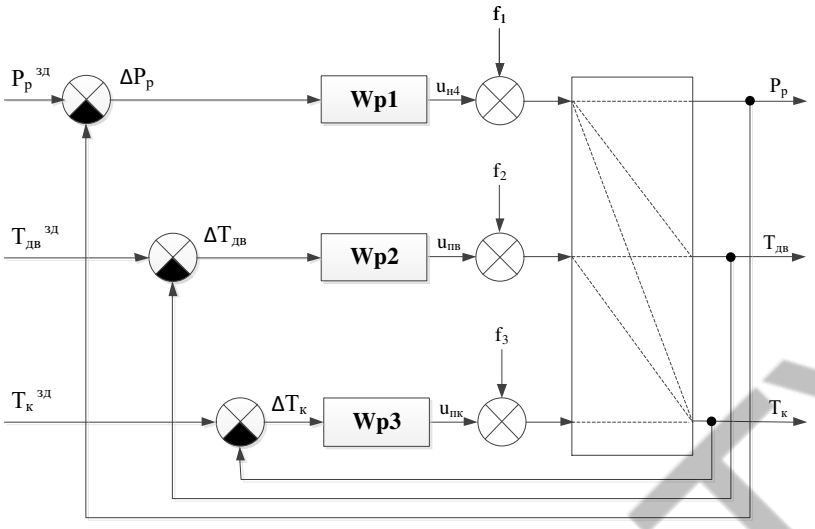


Fig. 4 – Structural diagram of the simplest structure for the study of a simulation model of the process of dealcoholization of wine in a stream in a plant with a thermoelectric heat pump like ok

Experimental obtaining of quasi-static modes of any OC by classical methods assumes an admissible number of variable levels for such modes, the transition between which is carried out in dynamic modes. This leads to the loss of information between the selected levels for the vacuum evaporator and condenser, the operation of which includes phase transitions of matter and gas, the discretization of static characteristics may not allow detecting the points of changing fundamentally important regimes. In addition, the organization of a classic experiment to obtain static characteristics is quite difficult, requires considerable time spent on transient processes and confirmation of the start of a new static process. Taking into account the above, experiments were organized to study the static properties of the vacuum evaporator and condenser model, which can be considered as obtaining quasi-static characteristics. Their essence consists in an alternate change with a constant, preselected, speed of the current value to the thermoelectric heater and cooler from 0-12A, and the frequency of rotation of the vacuum pump from 0-50Hz and registration of variable temperatures at the control points of the object (T_{dv} - temperature of the DV at the outlet of the evaporator , T_k - temperature in the condenser, P_p - pressure in the receiver).

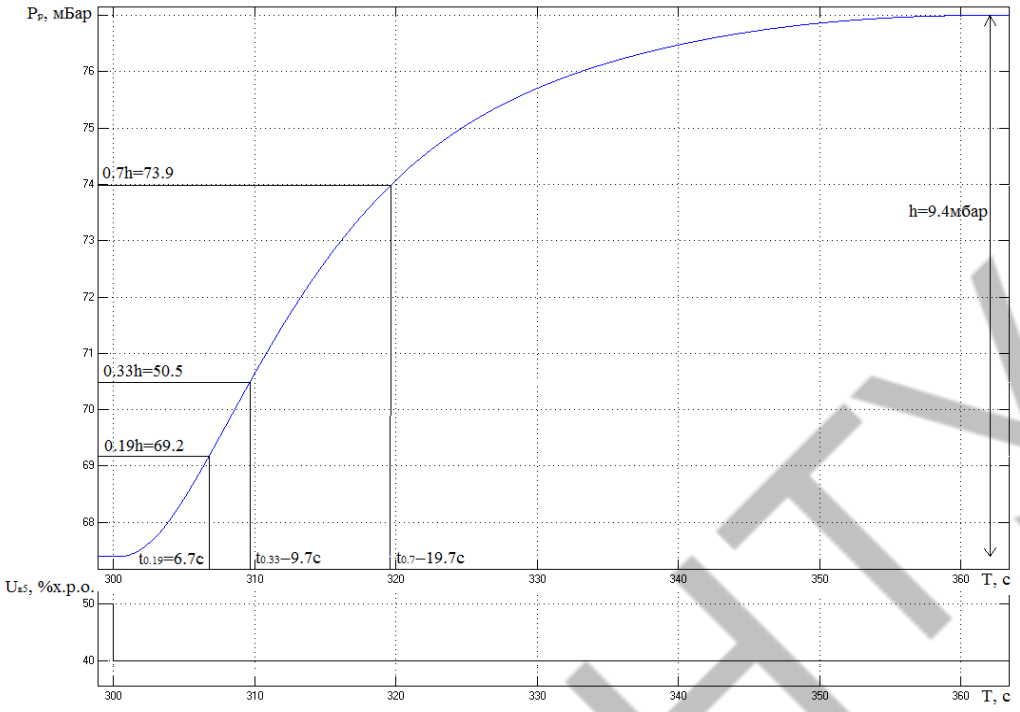


Fig. 5 – Response of the pressure in the receiver to a step change in the rotation frequency of the vacuum pump

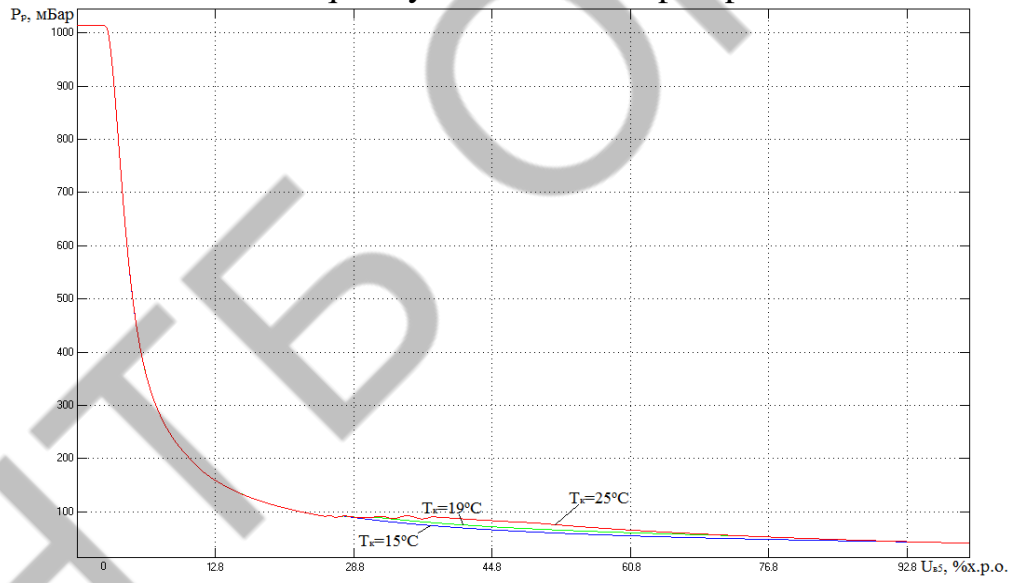


Fig. 6 – Quasi-static dependences of the pressure in the receiver on the frequency of rotation of the vacuum pump at different temperatures in the condenser

Figure 6 shows the quasi-static dependence of the pressure in the receiver on the frequency of rotation of the vacuum pump at different temperatures in the condenser. Such a static characteristic can be explained by the fact that at small rarefactions, the penetration (suction) of air is small, and the system appears to be astatic, but when the rarefaction increases, the suction increases and the system becomes static, that is, the flow rate of air penetrated into the device depends linearly on the pressure difference (atmospheric and rarefaction in the device). This explains the decrease in the pump transmission ratio.

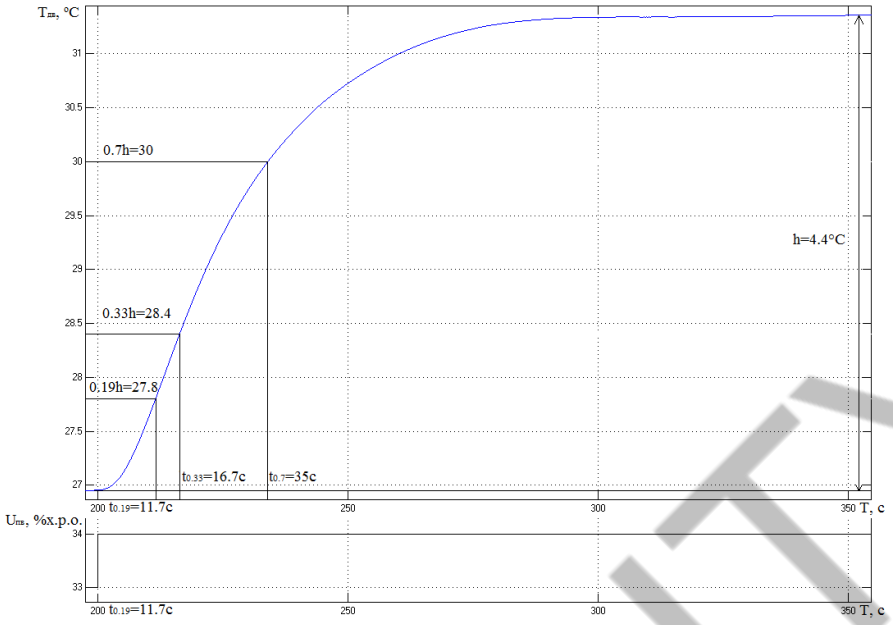


Fig. 7 – Reaction of the temperature of the DW at the outlet of the evaporator to a step change in the power supply current of the TEC of the evaporator

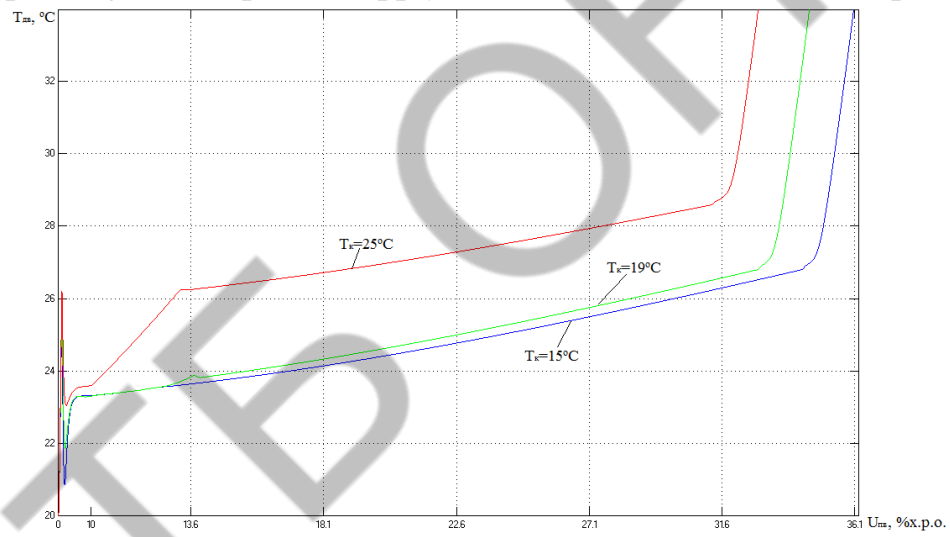


Fig. 8 – Quasi-static dependences of the temperature of the DW at the outlet of the evaporator on the supply current of the TEC of the evaporator at different temperatures in the condenser

Figure 8 shows quasi-static dependences of the temperature of the DW at the outlet of the evaporator on the TEC current of the evaporator at different temperatures in the condenser torus. The nature of these dependencies indicates that the temperature of the DW at the evaporator outlet is determined mostly by the pressure in the evaporator, which in turn depends on the pressure in the condenser and the pressure drop in the steam pipe connecting the evaporator to the condenser. This differential pressure depends on its hydraulic resistance and steam consumption from the evaporator. Also, a decrease in the temperature in the condenser causes a decrease in the energy efficiency of the thermoelectric heater. In the zone up to 33% and at $T_k = 19\ ^{o}C$, evaporation of alcohols is observed.

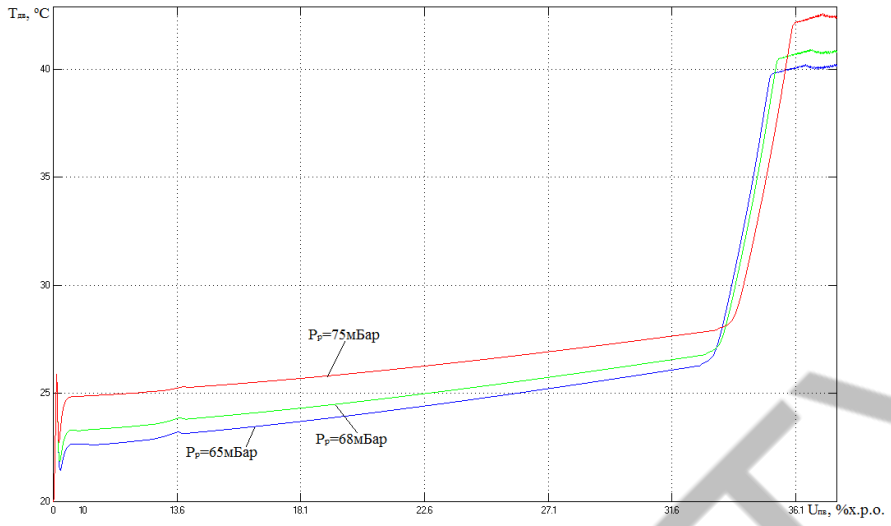


Fig. 9 – Quasi-static dependences of the temperature of the DW at the outlet of the evaporator on the power supply current of the TEC of the evaporator at different pressures in the receiver

Figure 9 presents quasi-static dependences of the temperature of the DW at the outlet of the evaporator on the power supply current of the TEC of the evaporator at different pressures in the receiver. The nature of these dependencies indicates that the temperature of the wine in the evaporator is determined mostly by the rarefaction in the evaporator, which in turn depends on the rarefaction in the condenser and the pressure drop in the steam line connecting the evaporator to the condenser. This differential pressure depends on its hydraulic resistance and steam consumption from the evaporator. In turn, the rarefaction in the capacitor depends on the pressure in the receiver. In the zone up to 33% and at $P_p = 68$ mBar, the evaporation of alcohols is observed.

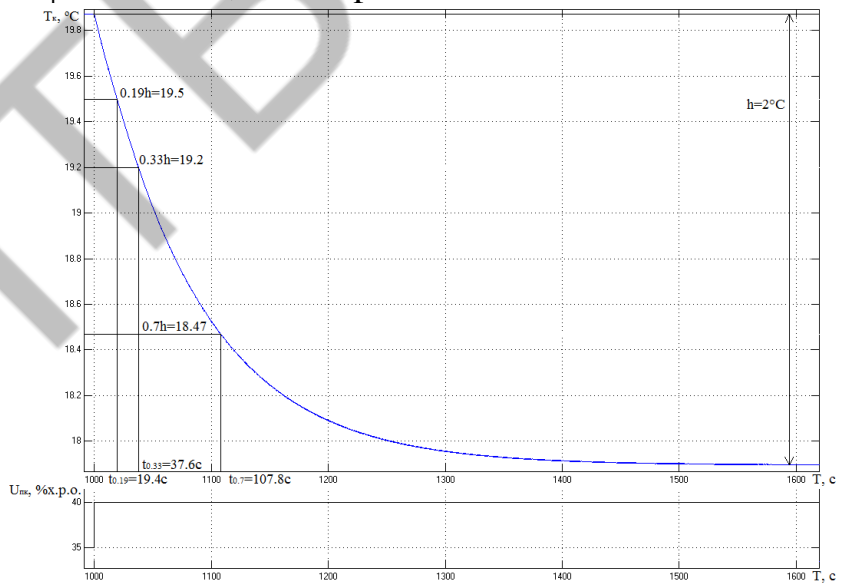


Fig. 10 – The reaction of the temperature in the capacitor to a step change in the power supply current of the TEC capacitor

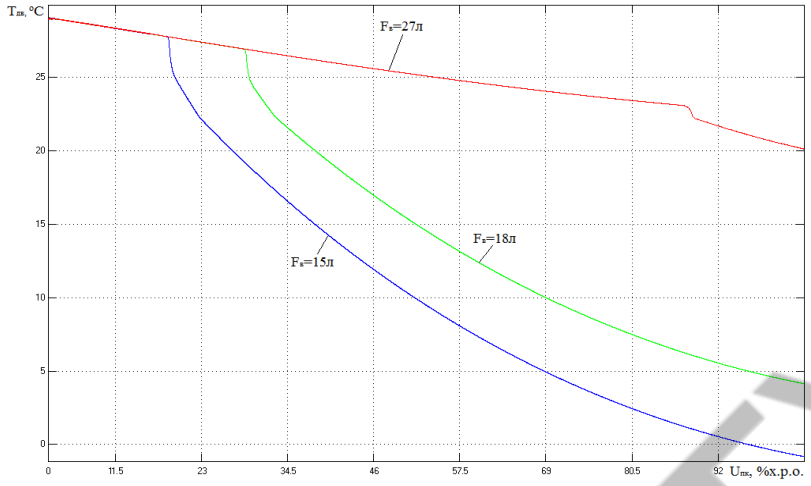


Fig. 11 – Quasi-static dependences of the temperature in the condenser on the power supply current of the TEC condenser at different consumption of wine material

Figure 11 presents quasi-static dependences of the temperature in the condenser on the power supply current of the TEC condenser at different consumption of wine material. The nature of these dependencies indicates that the temperature in the condenser is determined mostly by the amount of steam, which in turn depends on the consumption of wine material. Also, a decrease in the temperature in the condenser causes a decrease in the energy efficiency of the thermoelectric cooler.

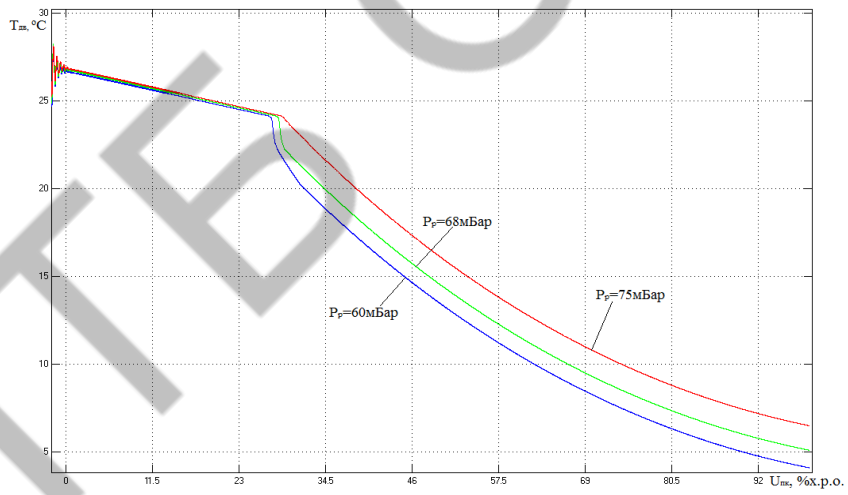


Fig. 12 – Quasi-static dependences of the temperature in the condenser on the supply current of the TEC condenser at different pressures in the receiver

Figure 12 presents quasi-static dependences of the temperature in the condenser on the power supply current of the TEC condenser at different pressures in the receiver. The nature of these dependencies indicates that the temperature in the condenser is determined by the vapor condensation temperature, which in turn depends on the pressure in the receiver. Also, a decrease in the temperature in the condenser causes a decrease in the energy efficiency of the thermoelectric cooler.

The results of parametric identification of the first-order model on the U_{pv} - T_{dv} channel.

$$K_0 = \frac{\Delta T_{дв}}{\Delta u} = \frac{31,3 - 26,9}{34 - 33} = 4,4 \; {}^{0}C/_{\%x.p.o.}$$

For the 1st order model

$$\tau_0 = 0,5 \cdot \left(3 \cdot t_{0,33} - t_{0,7}\right) = 0,5 \cdot \left(3 \cdot 16,7 - 35\right) = 7,4c$$

$$T_0 = \left(t_{0,7} - \tau_0\right)/1,2 = \left(35 - 7.4\right)/1,2 = 23c$$

The transfer function of the 1st-order OK model will look like this:

$$W_0(p) = \frac{4,4 \cdot e^{-7,4p}}{23p + 1}$$

The results of the parametric identification of the first-order model by the channel $U_{pk} - T_k$.

$$K_0 = \frac{\Delta T_к}{\Delta u} = \frac{19,9 - 17,9}{35 - 40} = -0,4 \; {}^{0}C/_{\%x.p.o.}$$

For the 1st order model

$$\tau_0 = 0,5 \cdot \left(3 \cdot t_{0,33} - t_{0,7}\right) = 0,5 \cdot \left(3 \cdot 37,6 - 107,8\right) = 2,5c$$

$$T_0 = \left(t_{0,7} - \tau_0\right)/1,2 = \left(107,8 - 2,5\right)/1,2 = 87,8c$$

The transfer function of the 1st-order OK model will look like this:

$$W_0(p) = \frac{-0,4 \cdot e^{-2,5p}}{87,8p + 1}$$

The results of the parametric identification of the first-order model on the U_{n4} -P_p channel.

$$K_0 = \frac{\Delta P_p}{\Delta u} = \frac{67,4 - 76,8}{50 - 40} = -0,94 \; мБар/_{\%x.p.o.}$$

For the 1st order model

$$\tau_0 = 0,5 \cdot \left(3 \cdot t_{0,33} - t_{0,7}\right) = 0,5 \cdot \left(3 \cdot 9,7 - 19,7\right) = 4,7c$$

$$T_0 = \left(t_{0,7} - \tau_0\right)/1,2 = \left(19,7 - 4,7\right)/1,2 = 12,5c$$

The transfer function of the 1st-order OK model will look like this:

$$W_0(p) = \frac{-0,94 \cdot e^{-4,7p}}{12,5p + 1}$$

4.3. Development and parametric optimization of regulation algorithms

Coordinate scheme of in-flow dealcoholization of wine using a thermoelectric heat pump shown in Fig. 2. According to it and to the structural diagram corresponding to the closed-loop control principle, the structural diagram of the ACS will have the form shown in Fig. 13.

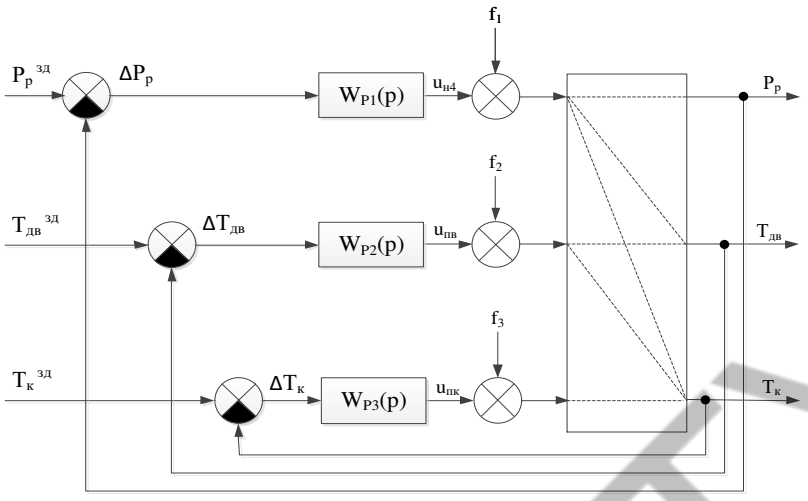


Fig. 13 – Structural diagram of the control system corresponding to the closed-loop control principle

In the picture in :

$u_{н4}$ – rotation frequency of the vacuum pump ;

$P_р$ – pressure in the receiver ;

$P_р^{ЗД}$ – a given value pressure in the receiver ;

$\Delta P_р$ – adjustment error _ pressure in the receiver;

f_1 – a vector of uncontrolled disturbances;

$W_{P1}(p)$ – the transfer function of the pressure regulator in the receiver ;

$u_{пв}$ – current of the thermoelectric heater ;

$T_{дв}$ – the temperature of the DW at the outlet of the evaporator;

$T_{дв}^{ЗД}$ – the set temperature value of the DW at the outlet of the evaporator;

ΔT_{dv} – temperature regulation error and _ wine in the evaporator;

f_2 – a vector of uncontrolled disturbances;

$W_{P2}(p)$ – the transfer function of the wine temperature regulator in the evaporator ;

$u_{пк}$ – the current of the thermoelectric cooler ;

$T_к$ – alcohol condensation temperature ;

$T_к^{ЗД}$ – the set temperature value _ _ condensation of alcohol ;

$\Delta T_к$ – temperature regulation error and _ alcohol condensation;

f_3 – a vector of uncontrolled disturbances;

$W_{P3}(p)$ – the transfer function of the alcohol condensation temperature regulator .

As a regulation algorithm, we choose proportional-integral-differential (PID) regulation algorithms.

The transfer function of the PID controller

$$W^P(p) = K_p \cdot \left(1 + \frac{1}{T_{ІЗ} p} + \frac{T_{УП} p}{0{,}2 \cdot T_{УП} p + 1}\right)$$

The structural diagram of modeling a three-dimensional ACS with a PID controller is shown in Fig. 14. The results of optimization of the PID controller settings are shown in Fig. 15. The results of checking the ACS for roughness are shown in Fig. 16.

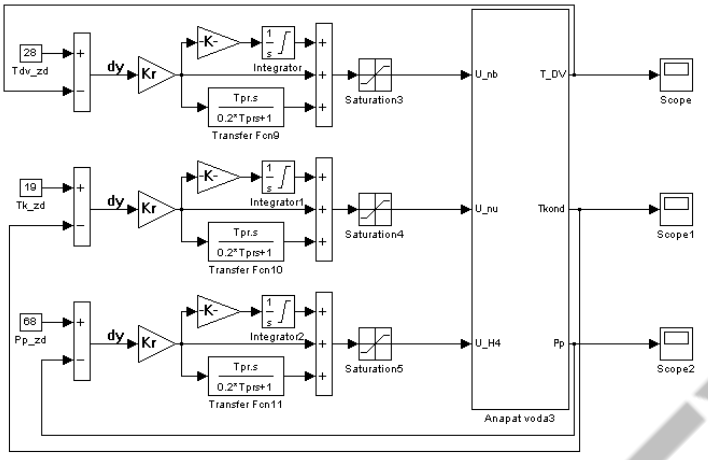
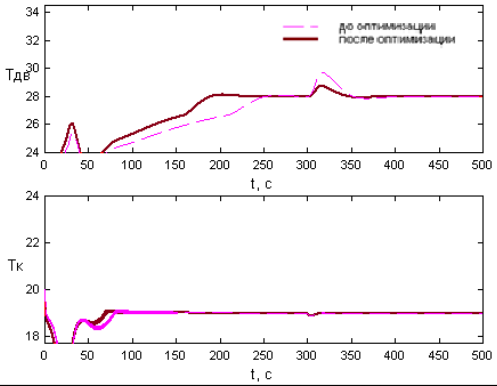


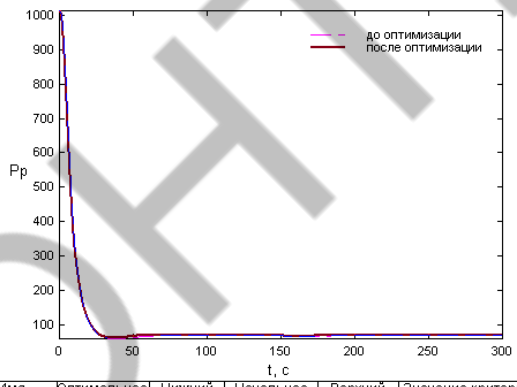
Fig. 14 – Structural diagram of the model of the ACS with PID controller



Имя переменной	Оптимальное значение	Нижний предел	Начальное приближение	Верхний предел
Kr1	0.81256	0	0.7	10
Tiz1	12.9226	0	14.8	30
Tpr1	7.1168	0	7.4	20
Kr2	-94.114	-100	-87.8	0
Tiz2	4.5818	0	5	20
Tpr2	2.4853	0	2.5	10

Значение критерия оптимальности:
до оптимизации - 50.819
после оптимизации - 20.4796

Количество шагов процедуры оптимизации:
максимальное - 500
фактическое - 21



Имя переменной	Оптимальное значение	Нижний предел	Начальное приближение	Верхний предел
Kr	-3.3133	-15	-2.8	0
Tiz	6.8933	0	9.4	20
Tpr	4.7	0	4.7	30

Значение критерия оптимальности:
до оптимизации - 38.1607
после оптимизации - 27.5817

Количество шагов процедуры оптимизации:
максимальное - 100
фактическое - 12

Fig. 15 – The results of optimizing the settings of the PID controller of the temperature of the DW at the outlet of the evaporator, the temperature in the condenser and the pressure in the receiver

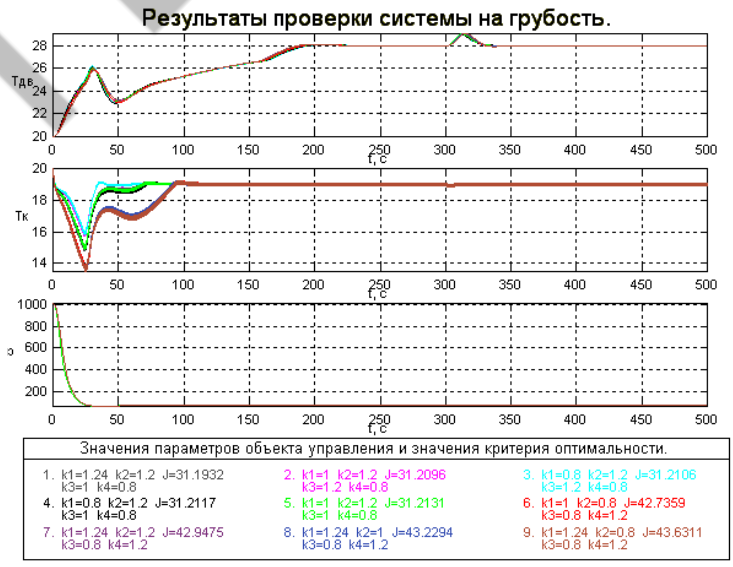


Fig. 16 – The results of the test ACS with PID-regulator for roughness

V. CONCLUSIONS

The scientific work was carried out in order to investigate the possibilities of increasing the efficiency of the automatic control of the energy-saving process of dealcoholization of wine in the stream in the installation with a thermoelectric heat pump by developing appropriate control algorithms.

The analysis, synthesis and parametric optimization of the ACS of the basic structure were performed. The developed ACS is implemented in the MATLAB Simulink environment.

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STUDY OF THE OPTIMAL STRATEGY FOR TESTING COMPLEX ML MODELS AND AI APPLICATIONS USING THE MLOPS CONCEPT

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Abstract: *In this paper, a study was made of the types of testing for software products using machine learning and intelligence technologies and their structuring. An analytical study was carried out to highlight the main shortcomings and ways to solve them. The entire process of software testing was analyzed, its types, stages and processes in the classical form were highlighted. After – there were recommendations for testing machine starting systems with the involvement of the MLOps methodology. Testing tools were analyzed and recommendations for testing ML models were provided. Knowledge of machine learning and its role in the development of modern IT technologies was structured.*

Keywords: *Software testing, Test strategy, ML models, AI-application, Test plan, MLOps, Types of testing.*

I. INTRODUCTION

Formulation of the problem. The world of modern IT technologies is constantly evolving. Every day there are new technologies that help humanity to live easier and better. We have come close to a new branch of the evolution of information technology – we can produce robotics, create the latest web applications, expand the boundaries of engineering. One of the manifestations of such a sustainable development of information technologies is artificial intelligence and machine learning.

Artificial intelligence is the ability of a system to correctly interpret external data, learn from such data, and use the knowledge gained to achieve specific goals and objectives through flexible adaptation. Now the use of artificial intelligence is highly valued, as a result, the demand for developers in this software area is growing rapidly. The main activities for the development of AI in Ukraine today is the construction of intelligent computer systems with integral intellectual behavior, an important property of which is adaptability to environmental changes. Developments are underway in the field of speech and visual recognition, intelligent robotics and modern telecommunication systems and mobile communication systems, systems for remote protection of objects.

Machine learning (ML) is a sub-branch of artificial intelligence in information technology that often uses statistical techniques to enable computers to "learn" (i.e., incrementally improve performance on a particular task) from data, without having to be explicitly programmable. Now this is a new technology that requires detailed study.

The essence of ML. Machine learning tasks tend to fall into two broad categories, depending on whether a training "signal" or "feedback" is available to the learner of the system.

There are many applications of machine learning today. For example, technology helps:

– to recognize the language of virtual assistants;
– to recognize handwritten letters;
– to define languages;
– to offer recommendations on websites;
– to look for documents
– to identify suspicious transactions;
– to predict the value of currencies;
– to analyze demand;
– to learn intelligent technique.

Machine learning technology is developing many different industries. Among the areas where it is used are business, medicine, the financial industry, industry and the IT sector. Like any software, ML systems and software developments for the use of artificial intelligence require testing to ensure the quality of the software product.

“Quality is the internal certainty of an object, which constitutes the specificity that distinguishes it from all others” – so it is noted in the explanatory dictionary of the Ukrainian language. In 1979 Crosby defined quality as "conformance to requirements", while Juran and Gryna in 1970 defined quality as "fitness for use". The giants of the IT industry, in pursuit of market leadership, pay special attention to quality, so software testing is an integral part of the software development life cycle. Considering how new and uncommon development area ML is, the demand for specialists of this level is very high [1].

The purpose of software testing, regardless of who tests it or where it is done, is to ensure the required quality of the software and to reduce the risk of program bugs. Therefore, the relevance of this work is to highlight the possible methods and techniques of software testing, to choose the most appropriate approach that can ensure the high quality of the software being developed.

In the structures of ML systems, it is difficult to single out the main "points" of testing and verifying a property, which is due to the huge data set that serves to develop the algorithmic grid of the entire system. The flexible methodology of MLOps helps to solve this problem [1].

MLOps – Machine Learning Operations, or DevOps for Machine Learning, is the bringing together of people, processes, and platforms to bring machine learning to business value. They simplify development and deployment by monitoring, validating, and managing machine learning models. The MLOps methodology is quite flexible, which makes it possible to test complex systems during their deployment and work with large databases [2].

Thus, there is a need to develop a software testing strategy, since by the current time there is no clearly defined testing plan for ML systems and applications using artificial intelligence technology.

The aim of the project is to analyse and research various of techniques and methods for testing ML models, as well as an experimental study of testing strategies for ML systems and AI applications to highlight the main shortcomings and ways to solve them.

To achieve the goals set, it is necessary to solve the following tasks:

– to analyze the features and possible risks when testing AI developments and ML models;

– to consider alternative software development testing methods;

– to plan a pilot study to evaluate the effectiveness of testing;

– to develop practical recommendations for solving the problem of software testing in the field of machine learning.

The scientific novelty lies in the improvement of the testing model for ML models and AI applications, which will be clear to all business units, through the use of the MLOps concept, which allows high-quality testing of complex ML systems.

Practical significance of the obtained results lies in the fact that the testing approach obtained as a result of the experiment can be used in the software development process, guaranteeing a high level of quality at the entire stage of the software development life cycle, namely in complex ML software models.

Thus, as a result of the pilot study, an actual test strategy for testing ML models and AI applications using the flexible MLOps concept will be formed, which, in turn, will allow getting rid of the so-called "technical debt" in AI applications.

II. ANALYTICAL REVIEW OF LITERATURE

Until recently, we were dealing with sizable amounts of data and very few models on a small scale. Now the situation is changing and we have to implement decision-making automation in the widest range of applications. Technological solutions in the form of developments on the use of artificial intelligence help in this. And of course, this goes hand in hand with a host of technical challenges that come with building and deploying machine learning systems.

Machine learning refers to artificial intelligence methods that teach a computer to independently solve different problems. Computers perform analytical work and identify patterns much faster than humans thanks to preloaded data and special algorithms.

Algorithms are determined depending on what problem needs to be solved and what data the developers have. A set of training data provides algorithms that process various queries with their help [2].

As a rule, computers require a large amount of information and statistics in order to learn how to make correct and necessary predictions.

In order to better understand the essence of machine learning, it should be understood that ML, like any other software area, consists of several basic equivalents (Fig. 1).

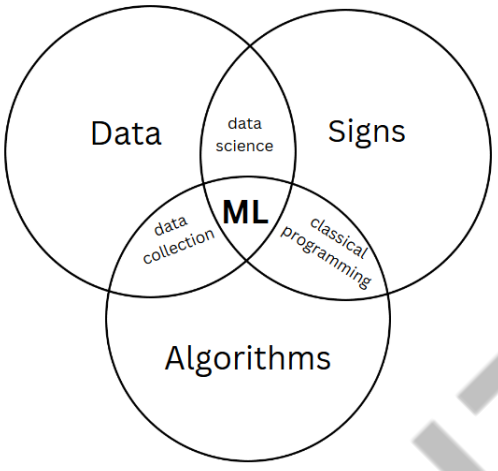

Fig. 1. Structural parts of machine learning

The first is data. In machine learning, data collection plays one of the most important roles. To train a single ML model, tens of thousands of examples are needed for the model to be able to provide a more accurate result. Of course, we must understand that checking and testing such a database is one of the tester's entry points.

The second is signs. In machine learning, signs, properties, characteristics are called "features". When training a model, it should be understood that the algorithm should pay attention only to what it needs. The more properties the algorithm knows, the slower the model runs. What to pay attention to in the end should be decided by the model itself, even if it often takes more time than training, but the initial data and possible parameters are given to it by a person, and a tester can also do this, even if it formally refers to data collection. Based on the input parameters, the algorithm will not pay attention, but we must provide the maximum picture of what we see with the input data.

The third is the algorithm. This is where developers work and write instructions for the machine learning model to work.

There are a lot of examples of modern use of ML. Machine learning is used to optimize search engines, improve work in the areas of service, medicine, and construction.

Like any software, ML modules need to be tested.

Generally speaking, testing is a technical research process designed to discover information about the quality of a product in relation to the context in which it should be used. Testing technique also includes both the process of finding bugs or other defects and testing software components for evaluation [3].

In software engineering, there are five main types of tests used at different stages of the development cycle (Fig. 2)

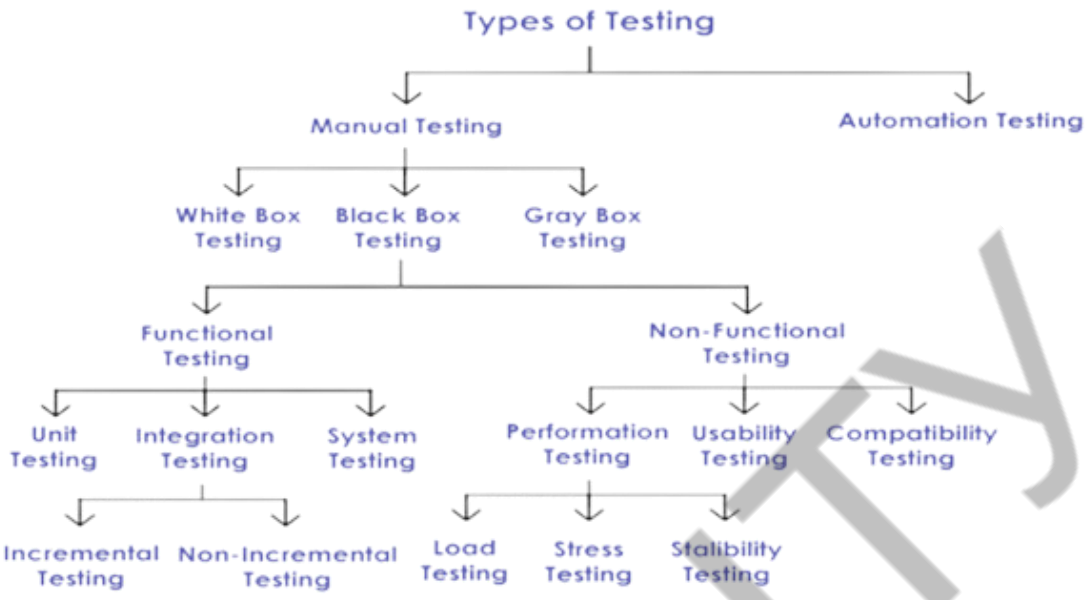

Fig. 2. Types of tests [4]

Unit tests for individual components, each with one area of responsibility and one end result, such as a list filtering function.

Integration tests for the combined verification of the combined operation of several individual components, such as data processing [4].

System tests to verify the design of the system as a whole by comparing expected results with input data;

Acceptance tests to verify that the requirements specified in the acceptance conditions are met are commonly referred to as user acceptance tests (UAT – User Acceptance Testing);

Regression tests to test previously known bugs to make sure new changes don't cause them again.

To structure and develop tests, it is recommended to use the 3A (Arrange-Act-Assert) approach, which orders inputs, actions, and results:

- Arrange – set up all kinds of inputs for testing;
- Act – apply the input data to the component under test;
- Assert – confirm the receipt of the expected result.

It should be understood that testing can be modified depending on which software area is being tested. With all the demand for machine learning, customers and executors of such projects often miss the field of testing in its classical sense. If insufficient attention is paid to testing, this can lead to incorrect operation of ML systems and cause customer disappointment in the technology as such. Of course, Data Scientists themselves check their models using special metrics, but the reality is that the service is not always able to take into account various nuances and production bottlenecks. Unfortunately, there are no well-established practices for testing ML services in the IT industry yet, therefore, when

selecting tests, we rely on our own expertise and experience of specialists, who know the industry specifics of the customer company. In classical testing, we can predict the result: how the system will react to certain input data. If we are talking about the use of ML in production environments, this predictable result can be compliance with regulatory documents: GOSTs, instructions, permanent and temporary technological maps that determine production processes and the quality of the final product. Testing allows you to make sure that the forecasts of the ML system do not contradict the regulations adopted by the enterprise. instructions, permanent and temporary technological maps that determine the production processes and the quality of the final product. Testing allows you to make sure that the forecasts of the ML system do not contradict the regulations adopted by the enterprise. instructions, permanent and temporary technological maps that determine the production processes and the quality of the final product. Testing allows you to make sure that the forecasts of the ML system do not contradict the regulations adopted by the enterprise.

One of the "outputs" in testing machine learning models of varying complexity is MLOps (Fig. 3).

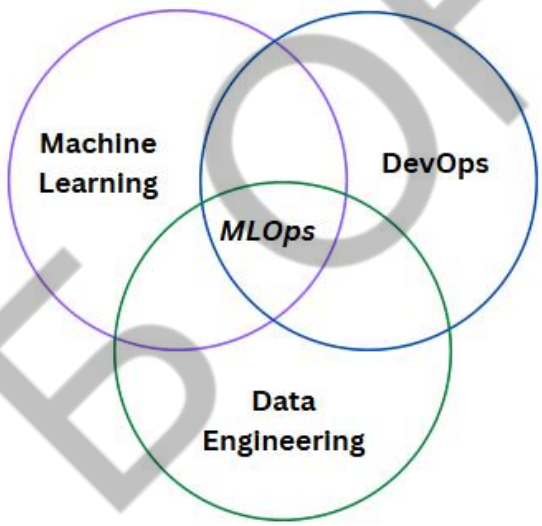

Fig. 3. The structure of the MLOps methodology

To better understand MLOps, we must first take a look at the life cycle of machine learning systems. This life cycle involves several development teams at once, covering different aspects of working with data.

In order to connect to the process, the following commands take part:

- Business development team or software product development team – defining business goals using key performance indicators (KPIs).
- Data engineers – data collection and preparation.
- Data science – designing machine learning solutions and developing models.
- IT or DevOps – deployment and monitoring with the data science team.

Managing such systems on a large scale is not an easy task. There are many bottlenecks to consider. The following are the main challenges that teams face:

- Lack of data scientists capable of developing and deploying scalable web applications. A new profile of machine learning engineers is emerging in the market these days to meet this need. Their business stands at the intersection of data science and DevOps.
- Change business goals in the model. Given the many dependencies on ever-changing data, the need to maintain model performance standards, and to provide AI-driven control, retraining a model in response to changes in business goals is not an easy task.
- Mutual misunderstanding between technical departments and business teams, which find it quite difficult to find a common language within the framework of joint work. More often it is this misunderstanding that causes the failure of large projects.
- Risk assessment. The nature of the black box of such machine learning and deep learning systems is a matter of constant debate. Models tend to deviate from what they were originally intended to do. Assessing the risk/cost of such deviations is a very important and careful step [5].

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The object of study is use of testing methods and strategies, namely MLOps testing methods, for comparative analysis of testing strategies

The subject of study is software models and implementations of machine learning.

The study methods. This analytical study presents methods and strategies for software testing. Comparison of these types and application to developments using learning art and artificial intelligence.

When testing complex systems and applications, you should remember the main specifics of testing a software product.

Testing processes determine whether the development products of a particular activity meet the requirements of that activity and whether the system and/or software satisfies the intended use and user needs. The objectives of the testing process are defined for different levels of integrity.

These process objectives define the breadth and depth of test documentation. You can then select documentation items for each type of test documentation.

The scope of testing includes software systems, computer software, hardware and their interfaces. This standard applies to software systems being developed, maintained, or used (legacy, COTS, undeveloped items).

Any testing has its artifacts. The first is a test plan.

A Test Plan is a document that describes the entire scope of testing work, starting with a description of the object, strategy, schedule, criteria for starting and ending testing, to the equipment required in the process, special knowledge, and risk assessment with options for resolving them.

Any methodology or process tries to impose its test plan design formats. If the standard template doesn't fit, or you need to come up with your own more specific document format, then you might be told that a good test plan should describe the following:

1) functionality to be tested - description of the test object: systems, applications, equipment;

2) functionality not subject to testing - a list of functions and a description of the system to be tested and its components separately;

3) testing strategy, namely: types of testing and their application in relation to the test object;

4) the sequence of work: preparation (Test Preparation), testing (Testing), analysis of the results (Test Result Analisys) in the context of the planned development phases.

5) criteria for starting testing:

– readiness of the test platform (test board);

– completeness of the development of the required functionality;

– availability of all required documentation.

6) test completion criteria:

– test results meet the product quality criteria;

– requirements for the number of open bugs are met;

– exposure of a certain period without changing the source Code Freeze (CF);

– exposure of a certain period without opening new Zero Bug Bounce (ZBB) bugs.

All types of software testing, depending on the goals pursued, can be divided into the following groups:

1) functional;

2) non-functional;

3) associated with changes;

Functional tests are based on functions and features, as well as interactions with other systems, and can be presented at all levels of testing: component or unit (Component / Unit testing), integration (Integration testing), system (System testing) and acceptance testing (Acceptance testing). Functional types of testing consider the external behavior of the system. The following are some of the most common types of functional tests:

– Functional testing (Functional testing);

– Security and Access Control Testing;

– Interoperability Testing;

Non-functional testing describes the tests necessary to determine the characteristics of the software, which can be measured by different quantities. In general, this is testing how the system works [6].

The main types of non-functional tests:

1) All types of performance testing:

- load testing (Performance and Load Testing);
- stress testing (Stress Testing);
- stability or reliability testing (Stability/Reliability Testing);
- volume testing (Volume Testing);

2) Installation testing;
3) Usability Testing;
4) Testing for failure and recovery (Failover and Recovery Testing);
5) Configuration Testing;
6) Security and Access Control Testing;
7) Localization and internationalization testing.

After making necessary changes, such as fixing a bug/defect, the software should be tested again to confirm that the problem has indeed been fixed. The following are the types of testing that should be performed after software deployment to confirm that the application is working or that a defect has been corrected:

- smoke testing (Smoke Testing);
- regression testing (Regression Testing);
- assembly testing (Build Verification Test);
- sanitary testing or consistency / serviceability testing (Sanity Testing).

Currently, there are many types of testing, there are also a large number of classifications of these types. The main classification of types of testing occurs according to program goals. The figure below shows the classification of testing types (Fig. 4).

Also, it should be understood that testing has a level structure. Testing at different levels is carried out throughout the life cycle of software development and maintenance.

The level of testing determines what tests are performed on: on a single module, a group of modules, or the system as a whole. Testing at all levels of the system is the key to successful implementation and delivery of the project [7].

Software testing levels describe the stages of software development when testing is carried out. Generally, there are four progressive levels of testing based on the area they focus on in the software development process: unit testing, integration testing, system testing, and user acceptance testing (UAT).

Risks arising from software testing:

PMBOK recommends managing risk in 4 steps:

1) Identification. Identify risks that may interfere with project objectives.
2) Analysis. Determine which of the identified risks are the most dangerous.
3) Layout. Plan for dangerous risks.
4) Monitoring and control. Keep the project plan and risk list up to date [8].

A distinctive feature of software testing using ML technology. In order to understand the differences, you need to understand how the system works. Is there any difference between classical algorithms/hardcoded logic and functionality based on ML models?

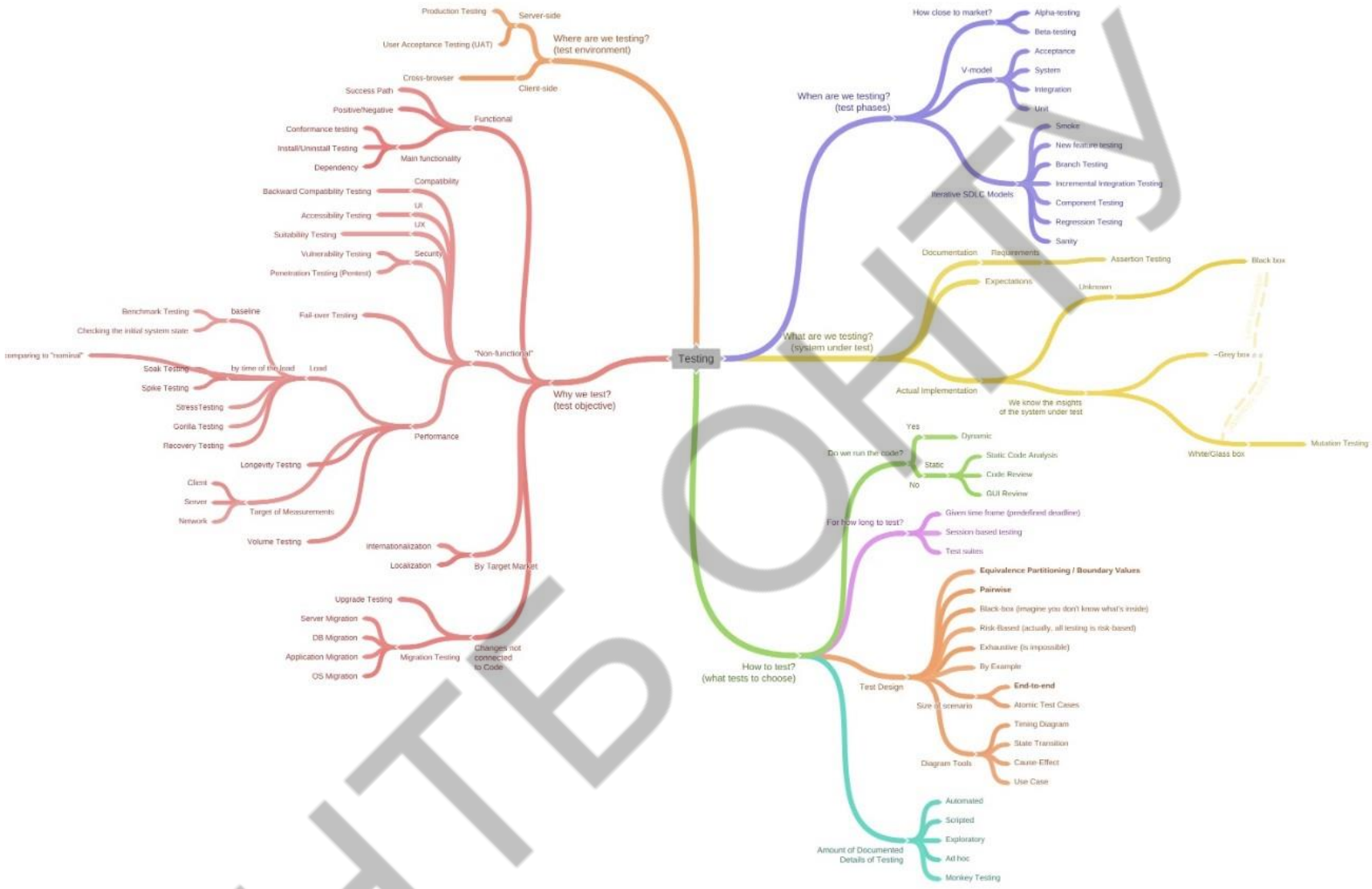

Fig. 4. Typical branching of the classification of types of testing [6]

From the point of view of the blackbox approach, this is still the same box with inputs and outputs.

However, inside the box, namely how the system is built, is somewhat different. The main difference is as follows:

When writing functions, we are guided by the rules that we set ourselves (traditional programming) or the function with its coefficients is selected by the algorithm based on the data we give it (machine learning).

Typical development process:

- Task formulation based on business requirements;
- Collection, cleaning and preparation of data (because garbage in – garbage out);
- selection of alternative learning algorithms based on the type of task, data availability and quality;
- Algorithm parameterization;
- Splitting the data set into training and test samples;
- Launching the training procedure on the required infrastructure;
- Iterative training with the required number of epochs, with regular testing on isolated test data samples;
- Preparing the model for production use (often involves reimplementation on another technology to optimize performance).
- Integration of model-based functionality in the production system.

Traditional QA occurs at the stage when the model has already been trained and it is possible to integrate it into the system:

1. Test cases have different test datasets. When testing, you should extract several data sets for this purpose. At the same time, the input data for the sample is not equivalent in importance: the voice assistant recognition function should work well for “call a child”, “what is the weather now”, and is rather less demanding in recognizing combinations such as “magneplanar headphone impedance”. Accordingly, to optimize the testing time, the data can and should be ranked.

2. If we have an ensemble of models that works well on a clustered sample, we need to cover each part of the aggregate model with tests. An example is credit scoring, where one model works for households with low total income and another for high-income families. The reason is simple: people's behavior is very different, different models better describe the end result.

3. If automation tools are used to implement regression control, the specified required level of acceptable deviation of the result, as well as the permissible level of outliers. Otherwise, the tests will regularly fail. Use metrics appropriate for the task type and conduct a mandatory data scientist review for test scenarios.

4. Be sure to check if the deployed ML function processes the data correctly (+/- inversion is common). The white-box approach works well here: use tests to check the correctness of loading the input data, check the feature outputs. The more complex the data preparation process and the more automated, the more closely you need to track it.

5. Data can mutate. This means that given the same input, a different output is now expected, such as user behavior has changed. A technically well-tested model will not become old over time, but it may not be usable.

6. Public beta - test - it's just a must for ml-based systems. The data used in both training and testing, the better your model will get. Important: The data should not be extrapolated. The more diverse the test data set, the more accurate the model testing process will be.

7. Pay attention to integration testing.

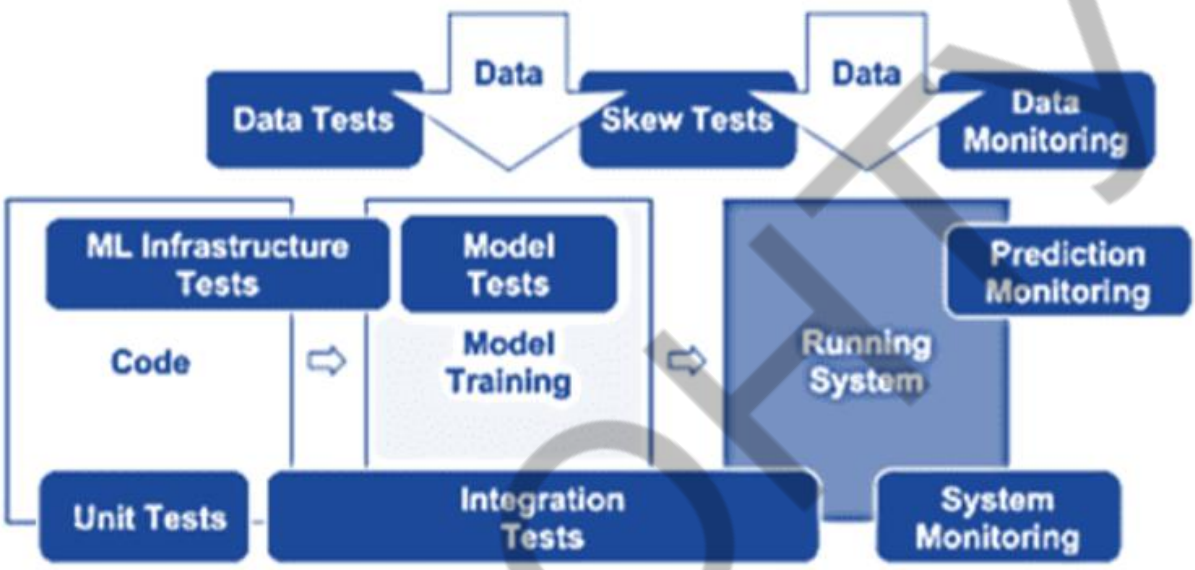

Fig. 5. Test objects in ML-system [10]

MLOps concepttries to take into account the specifics of the development, testing, deployment and operation of machine learning systems, integrating it with the best practices of software engineering.

The main task of the MLOps team is to automate the deployment of ML models in the main software system or as a service component [10].

Shown below (Fig. 6) is the end-to-end reference design for MLOps. It is important that the life cycle of MLOps is an iterative, not a linear process.

A failed test or compilation issue are examples of conditions for reverting to an earlier DevOps stage. MLOps inherits DevOps terms and adds new ones, such as offline validation and model drift, unique to machine learning.

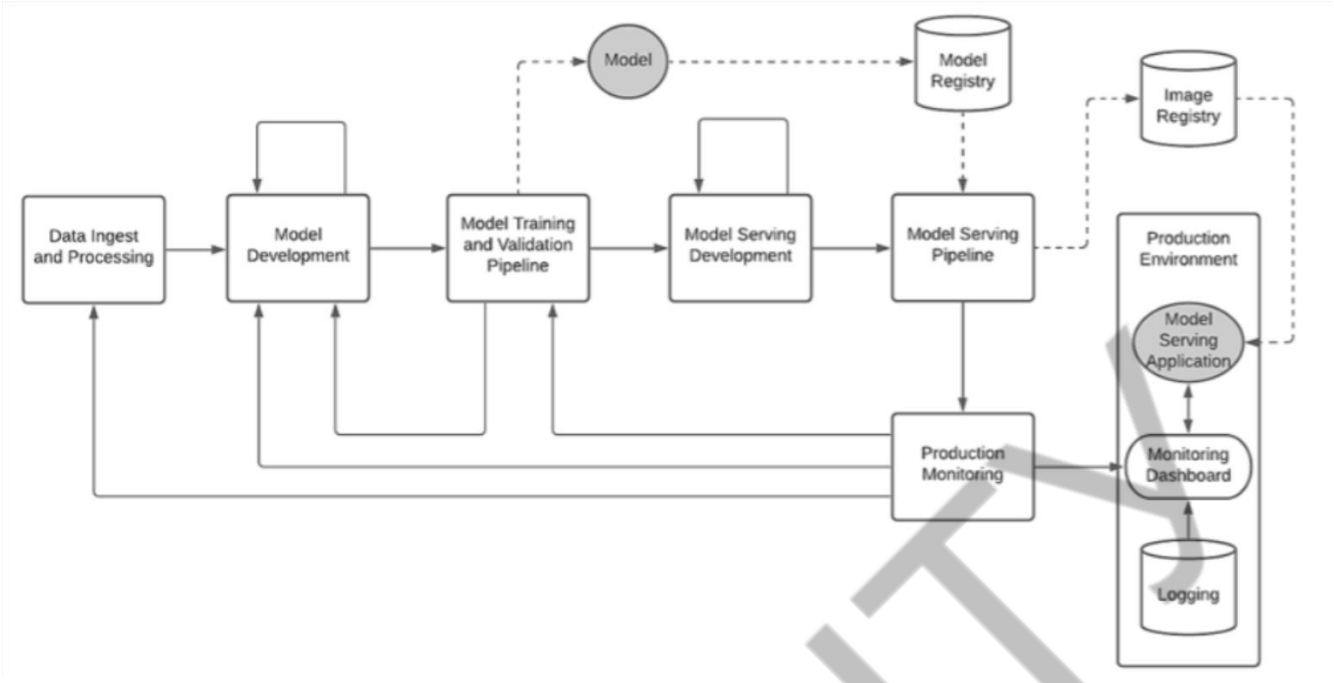

Fig. 6. Typical branching of the classification of types of testing [7]

IV. CONCLUSIONS

Using a step-by-step analysis of the available testing techniques and examining the largest machine learning models, we came to the appropriate conclusions and formed the appropriate recommendations for testing complex ML models:

1. Testing of ML models includes procedures that check whether the developed algorithm answers the request, which is formed depending on the business goals of the project. This means that the loss metrics of the ML algorithm (MSE, log-loss, etc.) must correlate with the business impact metrics (revenue, user acquisition, etc.). To measure the relationship between loss rates and impact rates can be measured through small-scale A/B testing using an intentionally degraded model.

2. It is recommended to test older models. A Machine Learning model is considered obsolete if it does not contain up-to-date data and/or does not meet business impact requirements. This is where A/B testing with outdated models can help to understand how often ML algorithms should be retrained. It is advisable to estimate the cost of more complex machine learning models by comparing the performance of, for example, a deep neural network with a simple linear regression.

3. To test the performance of the model, it is recommended to separate the commands and procedures that collect training and test data to remove dependencies and avoid propagating false methodology from the training set to the test set. This requires an additional test data set that does not overlap with the training and validation sets. This test dataset should only be used for final evaluation.

4. In order to assess the fairness of the model, it is necessary to collect as much data as possible, including potentially underrepresented categories, additionally checking the incoming features. Here, simple unit testing is suitable for creating any features, training and testing an ML model.

Also, we must define a step-by-step process for testing the ML infrastructure:

1. Training of ML models should be reproducible, that is, on the same data, it should give identical results. Various testing of machine learning models relies on deterministic learning, which is difficult to achieve due to the non-convexity of machine learning algorithms, random seed generation, or distributed learning of a machine learning model.

2. First you need to define the non-deterministic parts of the model training code base and minimize the non-determinism. Then check the stress testing using the ML API. Conduct unit tests to randomly generate input data and train the model with a single optimization step, such as gradient descent.

3. Crash tests should be performed to train a model that needs to recover from a checkpoint after a crash within training. Having checked the algorithmic correctness, you can proceed to the next step - unit testing, which is intended not to complete the training of the ML model, but to iteratively train it and reduce losses. It is recommended that you avoid testing differences with previously created models, as such tests are difficult to maintain.

4. The entire ML pipeline must pass integration testing through a fully automated test that runs it regularly. The test should confirm that the data and code successfully complete each training step and that the resulting ML model works as expected. All integration tests must be completed before the Machine Learning model gets into production. After running the model in production and before servicing it, the model should be validated by setting a threshold to check for degradation across different versions of the validation dataset. It is also necessary to check that the machine learning model is successfully loaded into the production environment, the prediction based on real data is generated properly. Ideally, the application of the Machine Learning model to the training and real samples should give the same prediction.

Despite the fact that the ML testing methodology has not yet stood firm, you can use popular tools to conduct it, such as:

– Jira for project management. In it, you can plan development, decompose tasks, and fix defects in an ML service.

– Test Rail for Quality Management. It allows you to conveniently store test scripts for the system, manage their runs and upload various testing reports.

– GitLab as a version control system.

– Jenkins for CI/CD and running autotests.

Prospects for further work are the development and creation of a complex system using machine learning technology for military rebuilding of buildings in Ukraine and the practical implementation of software testing based on selected work results [10].

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ORGANIZATION OF A BACK-UP CHANNEL OF COMMUNICATION IN A LOCATION WITH NO CELLULAR COMMUNICATION INFRASTRUCTURE

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Abstract. *In this work, we considered the organization of a backup communication channel with a remote point in emergency situations or in the absence of cellular communication. The maximum distance of information transmission was evaluated using several models of radio wave propagation. The battery life of the device is calculated. A prototype of the device has been developed.*

Keywords: *range of communication, LoRaWAN, Okumura-Hata, propagation of radio waves, communication in emergency conditions, rescue services.*

I. INTRODUCTION

The importance of information transmission as a provision of communication channels in the life of modern society is constantly growing. The development of communication technologies in the context of globalization is of primary importance and is taking place at an undeniably fast pace, growing in geometric progression, but it is mainly commercialized for the mass consumer and is represented by CDMA and GSM communication (Fig. 1) [1].

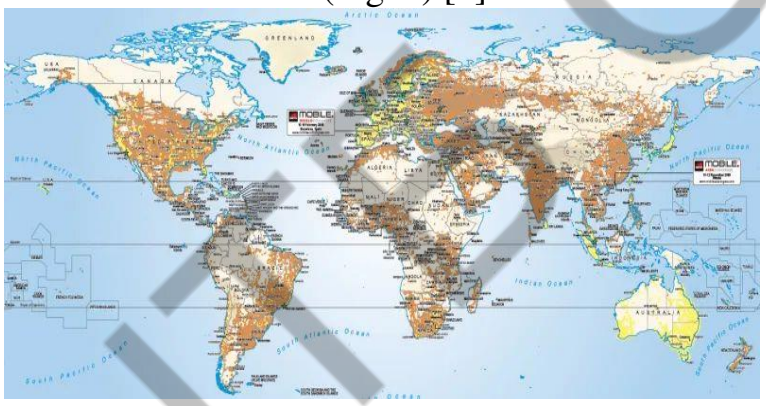

Fig. 1. Coverage of the Global System for Mobile Communications (GSM) in around the world for 2020.

If it is about identifying and saving human lives that are in danger due to force major circumstances - such as a plane crash, a shipwreck, derailment of a tourist group's route, conducting special intelligence operations in the fight against terror and reporting the necessary coordinates, then, unfortunately, the reality is this.

Lack of access to systems satellite and cellular communications due to obvious reasons in these circumstances or the possibility of its tracking (in conditions of rescue of hostages, for example) may cause human casualties. Therefore, it is objectively necessary to solve the problem of backup communication channels.

Even if devices for CDMA or GSM communication are available, there are still many areas on earth without coverage of these networks (Fig. 1.1). In the figure, we can see that even in highly developed countries, 100% is missing coverage of territories with communication. There are still many areas in the world, especially in developing countries, where researchers, tourists, people who have

suffered a ship or plane crash, and even the general public, may find themselves without communication, and therefore without help, in the event of force majeure.

Therefore, the development of backup communication channels is still relevant.

II. LITERATURE ANALYSIS

2.1 Existing backup communication systems for searching and rescuing people

At the end of the twentieth century, the COSPAS-SARSAT [2] people search system was developed. In emergency situations on ships and airplanes, a special device notifies about such a situation and the location of personal radio buoys installed on them. Any individual can purchase such a device for $350[3].

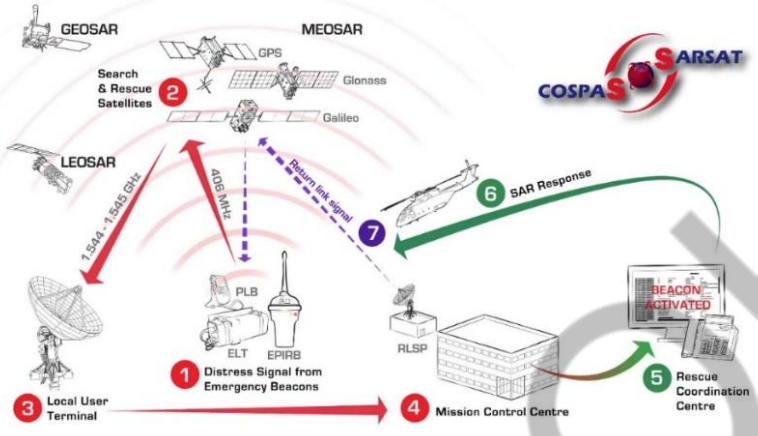

Fig. 2. Principle of system operation COSPAS-SARSAT

The principle of operation of the COSPAS-SARSAT system is that the coordinates of a place in this system are determined not on the ship by satellite signals, but at the shore station (information reception point) by the signals of a radio buoy relayed via a satellite. But even such a convenient rescue system has several drawbacks.

Not all countries have joined this alliance. The delay time for the delivery of information can reach up to 1.5 hours in the northern hemisphere and up to 2 hours in the southern hemisphere. There is also no feedback. The error of the system is about 20 km (if no GPS receiver is used), which is quite a lot. The presence of the listed shortcomings forces us to search for new directions for solving the problem of backup communication in an emergency situation for areas with no cellular infrastructure.

2.2 Alternative backup communication systems

To date, there are many systems for organizing communication in hard-to-reach places, all of them are quite different, starting from the fundamental difference and the necessary operating conditions and, of course, the cost of building and using such a system. One of the widely used such systems are radio stations, they enable the transmission of speech information in encrypted or open form over short, medium and sometimes quite long distances, depending on the class.

The most popular technologies used for backup communication can be classified as follows:

4) HF radio station
5) VHF radio station
6) Satellite communication

HF radio stations are transceivers operating at frequencies from 3 to 30 MHz. CV is divided into two subtypes. The first is a range that uses 3 - 25 MHz, which allows you to organize communication over long distances (transcontinental). And the second 25.6–30 MHz "Civilian" range is "Ci-B". The only range in which radio communication equipment can be used by private individuals without restrictions. The high range of communication in flat rural areas and the low cost of subscriber equipment make this range very attractive for various categories of users, from farmers, fishermen and shepherds to large construction, mining and transport organizations. Among the advantages, we can say the low cost of the equipment and the simplified registration procedure, which can be used by ordinary people.

VHF radio stations are stations for two-way transmission of ultra-short radio waves on ships, cars and ships to ensure the safety of work and movement. Unlike HF radio stations, portable VHF radio stations are smaller in size and weight than HF radios, have better autonomy, have a maximum range of about 10 km in open terrain, and a moderate price. The most popular brands of such radio stations are Icom, AOR, Kenwood, Motorola, etc.

Satellite communication is represented by the most common companies Iridium [4], Thuraya[5], Starlink[6] they have advantages - a very large coverage area, but some of them have a large mass (inStarlinkthe terminal weighs 8.5 kg) and volume, often the high price of the device and subscription (subscription fee), not much autonomy around the clock.

The problem of organizing backup communication at a distance of more than 10 km with affordable and compact terminals with high autonomy remains relevant. Longer range communication usually requires a fairly tall transmitter antenna to compensate for the curvature of the Earth and thus provide a line of sight. This is the main idea in this scientific work.

2.3 LoRaWAN trackers

LoRa is a new, spread-spectrum modulation method that allows low-speed data to be sent over long distances with minimal power consumption. LoRaWAN (Long Range wide-area networks) is the most well-known hardware protocol with LoRa, which is designed to manage communication between LPWAN gateways and end devices. More importantly, there are no access fees with this type of wireless technology. Therefore, some researchers [7-9] decided to use LoRaWAN technology to create GPS trackers. The LoRaWAN GPS tracker (GPS-LoRaWAN) is a battery-powered tracking device that uses the GPS satellite positioning service to determine its location and transmits the received coordinates using LoRaWAN radio technology. The intervals between measurements can be freely adjusted to adapt the device to individual needs. The built-in motion sensor detects changes in the movement of the device (if it is picked up or transported in a vehicle). This allows the device to switch between an active mode, in which frequent updates are downloaded during movement phases, and a sleep mode, which conserves battery power by sending only a few messages. Based on the specification [10] and the features of the LoRaWAN technology, we can conclude that it is quite a promising technology for the organization of backup communication in an emergency situation.

III. DEVELOPMENT OF BACKUP COMMUNICATION CHANNEL STRUCTURE BASED ON LORAWAN TECHNOLOGY

3.1 Object of research

The subject of research there is a set of theoretical and applied aspects of the mechanism organization of a backup communication channel with a remote point based on the LoRaWAN system.

User devices in LoRaWAN are divided into three classes:

– class A: after broadcasting, the device waits for a response from the BS, and then turns off the receiver until the next communication session;

– class B: the receiver of the device is turned on according to a predetermined schedule. The BS knows this schedule and therefore can transmit information to the device in accordance with it;

– class C: the receiver is always active, so the BS can transmit information at any time [11].

Strengths of LoRaWAN:

– due to minimal energy consumption for the transfer of small data packets, the energy consumption level of the end device is low;

– compared to other wireless technologies used for telemetry, radio signals travel long distances of 10-15 km in non-line-of-sight conditions and evidence of 766 km in line-of-sight conditions [12];

– in conditions of urban development, when using frequencies of the sub-gigahertz range, LoRaWAN has a high penetration of radio signals;

– no need to obtain frequency licenses and pay for the radio frequency spectrum due to the use of unlicensed frequencies;

– high scalability for large networks;

– relatively small cost.

Weaknesses of LoRaWAN:

– there are risks that the spectrum of the unlicensed frequency range may be noisy;

– the LoRa modulation technology is currently closely supported only by the patent of the Semtech company, which causes the impossibility of its application without this company;

– limiting the maximum signal power [13].

The network based on LoRaWAN consists of terminal devices (End-Device), gateways (Gateway), network servers (Network Server) and application servers (Application Server) (Fig. 3 a). The terminal device sends data to the gateway (Uplink), the gateway forwards it to the network server, and the network server forwards it to the application server as needed.

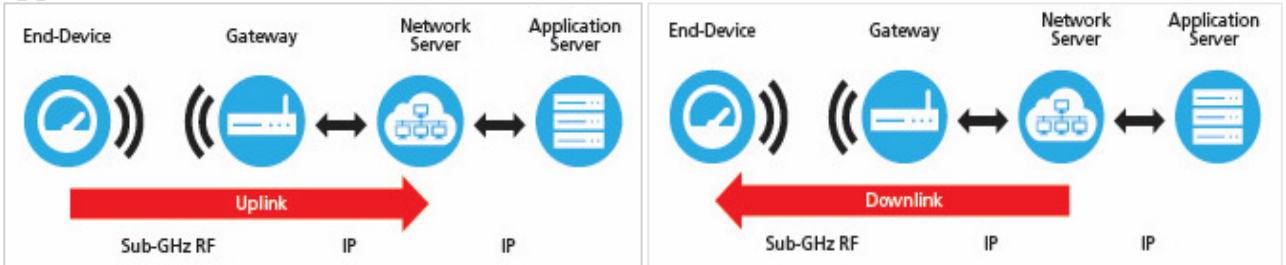

Fig. 3. LoRaWAN transmission: a - Uplink transmission, b - Downlink transmission

In addition, the network server can send messages (for network management or on behalf of the application server) to end devices through the gateway (Downlink) (Fig. 3. b).

Table 1 a contains summarized data for various parameters in the European frequency range.

Table 1. LoRaWAN specification

Parameter	Value
Frequency range, MHz	863-870
Maximum number of channels	35
UL radio signal spectrum width, kHz	125/250
DL radio signal spectrum width, kHz	125
Modulation	LORA, GFSK
Transmission power UL, dBm	2-14 20 (optional)
Transmission power DL, mW	1-25 100 (optional)
Transmission power DL, dBm	14
SF spectrum broadening factor	7-12

Consider the operational communication system, which is built on the basis of the LoRaWAN standard. Their main feature is a long range of communication with a rather small transmitter power, which determines the good autonomy of the device. Since the radio modules have very little power, there is no need for a radio amateur license and there is no need to register modems with national organizations responsible for spectrum managers.

The principle of maximum simplicity and cheapness of the solution is embedded in the concept. The structure of such a system should look as follows: client device of the sender; the LoRaWAN transmitter is equipped with a Bluetooth module for receiving information; base station (BS); recipient's client device.

Let's consider options for the development of events in which it is possible to use the communication system on based the LoRaWAN standard. Figure 4 simulates three situations of searching for a person or a group of people who are lost. They were previously issued with a LoRaWAN mobile transmitter.

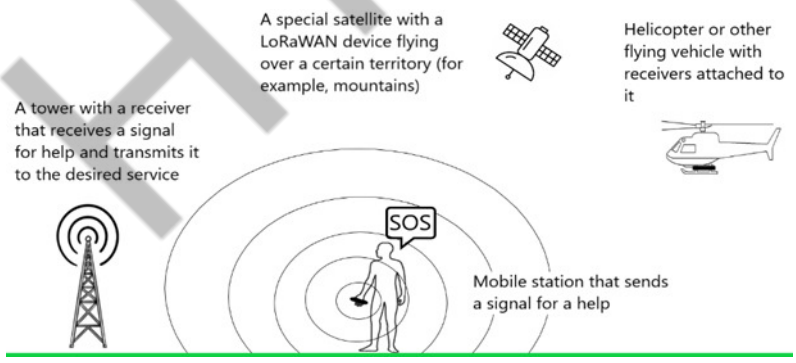

Fig. 4. Schematic view of the coverage organization for mobile transmitter communication

There are three ways to receive SOS signal, each type has its own advantages and disadvantages. The first is to locate ground base stations in a certain area (for example, in mountains or dense forests). The second is to send a helicopter or other aircraft over the likely location of those who are lost.

And the third is to use a satellite or a group of satellites that will constantly monitor the situation over a certain area. Each of these methods has its advantages and disadvantages.

To achieve a better result and a longer range of the alarm message transmission, the transmitter (or transmitter antenna) should be as high as possible relative to the Earth. Due to the light weight and compactness of the device, it can easily be thrown up using a special slingshot, which will be included with the device. An analogue of such a slingshot is usually used for fishing, it is capable of shooting at a distance of up to 400 meters [14], so it can easily raise the device to a height of about 30 meters to transmit information.

Also, to achieve a better result, due to the stability of the height, you can attach the device to quadcopter, and raise to the height necessary for direct visibility conditions. To select the moment at which information needs to be transmitted, the device will be equipped with an accelerometer to monitor the peak flight height of the transceiver in the air.

The typical transmission time of one message, depending on the channel settings, is from 0.1 to 2 s. Accordingly, the transfer speed is quite low - from approximately 100 Bit/s in the most long-range mode (far, but slow) to 20 kBit/s in overclocked mode (fast, but not far). Therefore, unfortunately, at such speeds there can be no transfer of media content, such as images or even more so video. The task of the developed system is simple - to send the shortest possible SMS message with the subscriber's coordinates and receive a response.

3.2 General description of the message transmission process

The system requires the equipment described in Fig. 5, as well as a client device for uploading information to the transmitter. It can act as a smartphone equipped with a Bluetooth module and on which special software is installed.

Message transmission process:

1. The sender is included in the application;
2. Connects to the device using Bluetooth;
3. Selects the required mode of operation (information transfer);
4. Enter a message in the text field;
5. After saving the message, the information is transmitted via Bluetooth to the LoRaWAN module;
6. The device rises into the air to the height required for direct visibility with the help of quadcopter, or on the most possible with the help of a slingshot;
7. In flight, the accelerometer measures the acceleration, and when it drops to a certain value, it transmits a signal to the LoRaWAN module;
8. The LoRaWAN module sends a message to the BS.

Points 1-5 need to be performed only in case of sending a random message. If it is enough to send a standard message, for example, "SOS, Full name (or pseudonym), my coordinates: 49.9808100° 36.2527200°", then for this you need to press a special button on the transceiver itself.

The base station works in reception mode and, after receiving a message, forwards it to the rescue service. A computer, laptop or tablet that has a direct local

connection to the base station or to a cloud server via the Internet can act as a client device for the recipient of an alarm message.

3.3 General description of the process of receiving a message

Since most of the time the device is quite low and cannot immediately receive an arbitrary message from the base station, a mechanism is needed to send a delayed message. In order to send messages when the receiver is at a height sufficient for reception, it is necessary to develop an algorithm for the operation of the base station.

As a solution to the above problem, we offer the following synchronization algorithm:

1) The sender (on the BS side) selects the recipient and downloads the information;

2) Information is stored until the BS receives a signal from the device that it is ready to receive data;

3) In the mobile application, the user selects the "Receive message" operating mode;

4) The device rises into the air to the required height;

5) In flight, the accelerometer measures the acceleration, and when it drops to a certain value, it transmits a signal to the LoRaWAN module;

6) The LoRaWAN module sends a 1-bit message to the BS, which signals readiness for reception, and immediately switches to reception mode;

7) After receiving the BS signal, it automatically transmits the saved information after the shortest pre-arranged time;

8) The receiver connects the phone / tablet / laptop via Bluetooth to the device and receives the message.

It should be noted that the procedure described above is for receiving an arbitrary message from the base station (rescue service). To receive the standard message, for example, confirmation of message delivery, it is enough to watch the LED on the transceiver body.

That is, in most cases, the basic functionality of the system remains functional even without a working smartphone.

3.4 Development of the hardware part of the device

Figure 5 shows a functional diagram from which you can understand that we need the same components to build the final device: The LoRaWAN module is equipped with an antenna; The Bluetooth module is equipped with an antenna; The GPS module is equipped with an antenna; accelerometer; battery with a battery charge control module (if necessary). The LoRaWAN module has three main requirements: maximum compactness, the presence of a connector for connecting the battery, and support for the SF 12 parameter to ensure the maximum transmission range. All the above requirements are met by the RAK 3244 BastWAN card.

The communication board RAK 3244 BastWAN - for wireless switching of IoT devices weighs only 6.9 grams, and is built on the RAK4260(H) module.

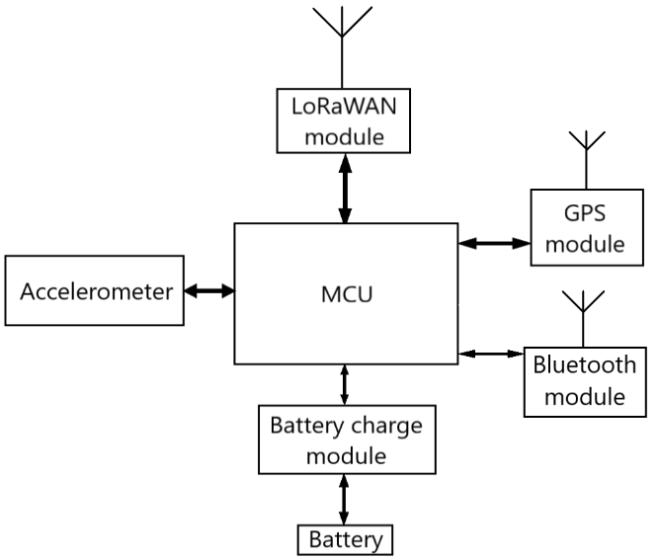

Fig. 5. Functional diagram of the device

The latter includes a Microchip SAML21 32-bit ATSAMR34J18 SiP processor consisting of several cores: ARM Cortex M0+ 48MHz and a LoRa SX127x transceiver. RAK3244 is compatible with the LoRaWAN 1.0.2 specification and supports Point-to-Point communication. LoRa low power consumption and broad communication capabilities make it suitable for many Internet of Things (IoT) applications, such as home automation, sensor and sensor networks, building automation, personal networking applications, and more.

GPS receiver - a radio receiver for determining the geographical coordinates of the current location of the receiver's antenna. GPS Click LEA-6S [15] is suitable for our purposes. Due to its small size, 3 modes of operation and low price. Bluetooth is a standard communication protocol that is primarily designed to be low power with a short range based on low-cost receiver microchips in each device. Since the devices use a radio communication system (broadcasting), they should not be in the direct line of sight of each other [16]. For the prototype of our device, let's stop at Bluetooth version 5.0 on the nRF52810 chip, which is installed on the HOLYIOT-21014 module and which we will consider next.

An accelerometer is a device that provides the ability to measure and analyse linear and angular acceleration. This device is needed with our device to track the peak point during the flight of the beacon and start sending a signal to ensure the maximum coverage area. You can also add an emergency tracking function so that if a person starts moving fast in a certain direction and brakes suddenly with overloads above a critical value, the accelerometer will detect it and activate the transmitter to send SOS signal.

The main requirements for the accelerometer module for the device are maximum energy efficiency, compactness and affordability. One of the possible options that satisfies all of them is the HOLYIOT-21014 module equipped with an LIS2DH12 accelerometer. HOLYIOT-21014 is also equipped with a Bluetooth 5.0 module built on the nRF52810 chip, and despite all this, the dimensions of the entire module are only 25 mm x 25 mm [17].

3.5 Device for increasing the height of the transmitting antenna of a mobile station

The next objective stage of consideration of our topic is the determination of the question of how the mobile station will be launched into the air and transmit information. To solve this problem, it is possible to use a quadcopter or a slingshot as

a device for launching a mobile station. Below are the technical characteristics of some of them.

Table 2. Comparative characteristics of quadcopters and slingshots

	Quadcopter	**Slingshots**	
Model	DJI MAVIC 3	Slingshot with coil	SlingFish B
Maximum lifting weight	200 gr	200 gr	250 gr
Price	$4,814.62	$19.86	$20.40
Maximum range	32 km	300 m	250 m
Maximum flight time	45 minutes	-	-
Max. flight height	6000 m	-	-
Dimensions	347.5×283×107.7 mm	16.8x11.2 cm	15.8 11.4
Weight	900 gr	442 gr	215 gr

Let's consider the positive and negative aspects of using these devices in the conditions of a tourist trip or searching for missing people as a result of a plane crash, etc. For quadcopters, the "plus" is a long flight range; the possibility of aerial reconnaissance; and "cons": high cost; lack of possibility of urgent repair; considerable dimensions. When using a slingshot, the advantage is low cost, small dimensions and weight, components are easily replaced and inexpensive. And the disadvantages are the small flight range of the object relative to quadcopters. Based on these results, it can be concluded that in the specified conditions, the slingshot has many more advantages over the quadcopter due to its weight, price and volume.

3.6 Design of the alarm transceiver

After all the necessary components are selected, you can proceed to the housing in which the product will be located.

When designing, it is necessary to take into account the shape of the case, so that when it is launched from a slingshot, the product has minimal aerodynamic resistance and does not interfere with height gain. It should also be taken into account that after such a launch, all internal components must remain intact, that is, the case must be impact-resistant and withstand a fall from a height.

That is, the main requirements for the case are as follows: maximum impact resistance; minimum size; aerodynamic shape.

In addition, if you develop a mechanism for which the product will descend as smoothly as possible after being thrown up, it will provide additional time for the transmission of information and, at a lower speed of fall, will reduce the risk of damage to internal components.

To ensure an aerodynamic shape, we suggest using a cylindrical shape with a cone-shaped antenna. Such a form is able to provide predictability in the air at the moment of gaining altitude and at the moment of falling. It also makes it possible to place the components well inside, so the accelerometer + Bluetooth module can be placed at the base (bottom) of the cylinder, the LoRaWAN radio module and the battery in the middle, and the antenna of the radio module can be removed from the top of the cylinder. Since the antenna can be in the form of a spring (Fig. 6), it can take a shock when it falls on itself and provide cushioning. For additional cushioning, the inside of the antenna can be a soft foam material, such as that used in the soles of modern sneakers.

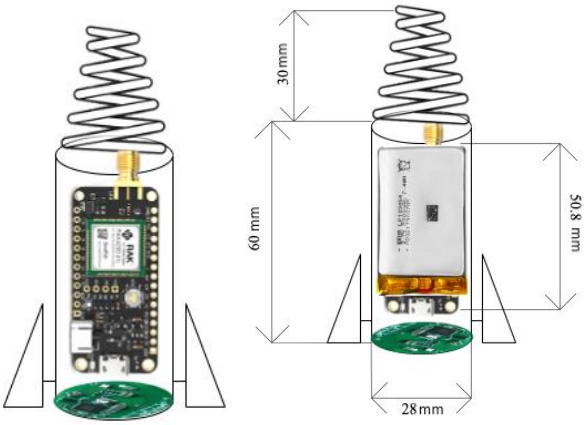

Fig. 6. Placement of components in the case

We offer a simple mechanism with wings that open when falling. At the moment when the product has reached its peak height and free fall begins, the accelerometer reports this, the latch releases the clamped spring, which opens 2 wings at an angle of 45°.

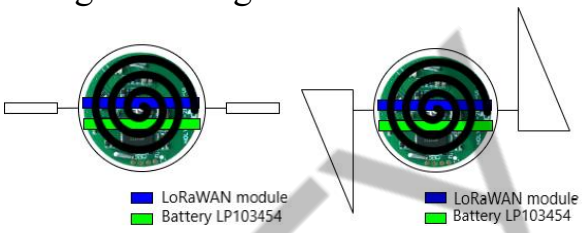

Fig. 7. Top view of the device with closed and open wings

Thanks to this design, the device will start to spin, which will reduce the speed of its fall. The spring is retracted by returning the wings to their initial position.

IV. RESULTS

4.1 Calculation of device autonomy

To choose the optimal power source (battery), it is necessary to calculate the energy consumption of the system and the desired autonomy. The autonomy calculation was performed according to the algorithm shown in Fig. 9.

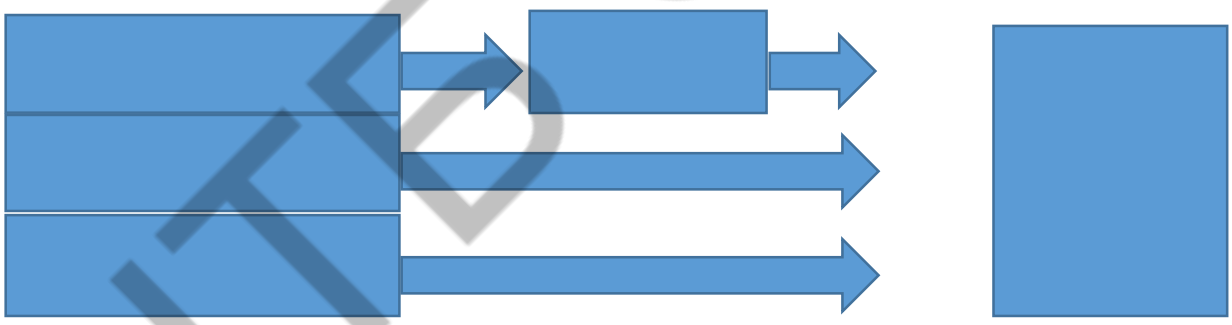

Fig. 9. Algorithm for calculating device autonomy

To perform calculations, you need to consider the energy consumption of all structural elements of our device for different modes (states). The data for the main components of the devices are given in Table 3.

Table 3. Energy consumption of the main structural elements of the device

Regime	**Microcontroller**	**GPS receiver**	**LoRaWAN modem**
Sleep	130 · 10-6	0.3 · 10-6	0.2 · 10-6
Measurement	230 · 10-6	1.5 · 10-6	0.2 · 10-6
Transfer	230 · 10-6	0.3 · 10-6	29 · 10-3
Acceptance	230 · 10-6	0.3 · 10-6	10.8 · 10-3

The results of calculating the autonomy of the device when powered by the LP103454 battery (2000mA) are shown in Fig. 10.

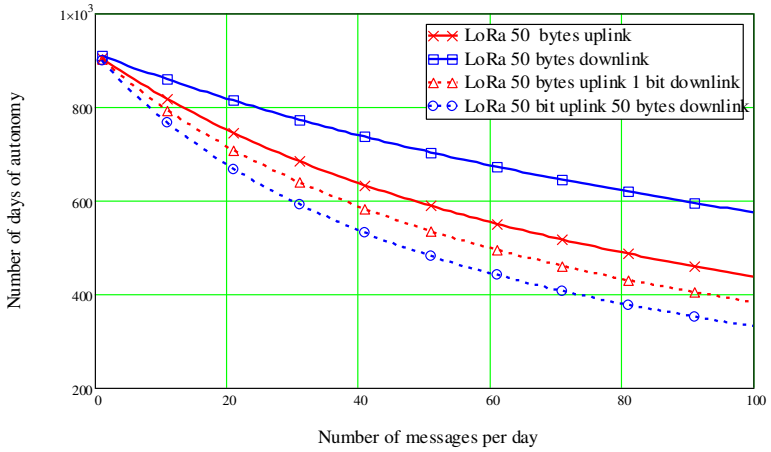

Fig. 10. – Dependence of the number of days of autonomy of the ZP on the number of messages per day

Analyzing this graph, we can say that when using a LiPo battery with a capacity of 2000mA, the autonomy of the device will reach approximately 330 days without recharging, under conditions of transmission and reception of 100 messages per day, each 50 bytes in size.

4.2 Assessment of the maximum range of information transmission

When designing a system that transmits information over a radio channel, the maximum distance between the transmitter and the receiver is one of the most important parameters that will have the greatest impact on the system design process. Selection of the correct communication range allows you to avoid increasing the output power, using repeaters or amplifiers. When creating a radio communication system, you must always strive to ensure the maximum distance. If the communication range is too long, it makes sense to reduce the output power and, as a result, the current consumption.

Choosing the optimal system frequency in the ISM range (0.169...2.4 GHz) is not always obvious. Antenna characteristics and location, regulatory limits on maximum output power, unwanted sources of interference, operating frequency, radio configuration, and propagation attenuation all determine the maximum distance between receiver (Rx) and transmitter (Tx).

Since the information transmission technology has already been chosen, it is necessary to rely on its existing technical characteristics listed in table 3.1.

4.2.1 Conditions of direct visibility

To calculate the maximum, we will use the empirical formula of line of sight LoS[18]:

$$R = 4{,}12 \times \sqrt{(ha + hp)} \qquad (4.1)$$

Where *ha*— lift height transmission antennas,

hp — elevation height of the receiving antenna.

In Table 4. assume several communication scenarios when the alarm signal transmitter is on the ground (for example, a person is unconscious), at a height of 1 m and 2 m (in equipment or in the hands of a person), 20 m (the transmitter is thrown up using a slingshot or a compact quadcopter) and for different heights of the receiving antenna (base station), for a ground base station (10m and 30m) and an aerial base station, such as a quadcopter or helicopter (100m and 5000m).

Table 4. The maximum range of information transmission in various conditions

ha/ hp	**10 m**	**30 m**	**100 m**	**5000 m**
0 m	13 km	22 km	41 km	291 km
1 m	13.66 km	22.93 km	41.4 km	291.35 km
2 m	14.2 km	23.30 km	41.6 km	291.38 km
20 m	22.56 km	29.13 km	45.13 km	291.91 km

To clarify the results, we will use the Fries model, which is used to determine the distance d of radio systems in an open environment and free space and can give estimated results for real systems with highly raised antennas:

$$\underset{Friis}{Pr} = Pt * \frac{G_t * G_r * \lambda^2}{(4\pi)^2 * d} \quad (4.2)$$

where: $\underset{Friis}{\Pr}$ - signal strength at the receiver input;

Pt - transmitter power;

G_t - the gain of the transmission antenna;

G_r - the gain of the receiving antenna;

λ –wavelength.

The optimal set of parameters of the LoRaWAN protocol is selected to calculate the power at the receiver input and subsequent comparison with the threshold sensitivity, which allows to calculate the range of the communication channel. One of these parameters is SF (spreading factor) - a coefficient to which transmission and reception parameters are tied. SF is a whole number, in the standard it is provided from 12 to 7. The higher the SF, the better the protection against interference in the radio channel and, accordingly, the greater the range, but the lower the speed and, accordingly, the longer the transmission takes on the air. According to the specification [19], the sensitivity of the LoRaWAN receiver, depending on the parameter SF, is in the range from -118 to -136 dBm.

The calculation results are shown in Fig. 11.

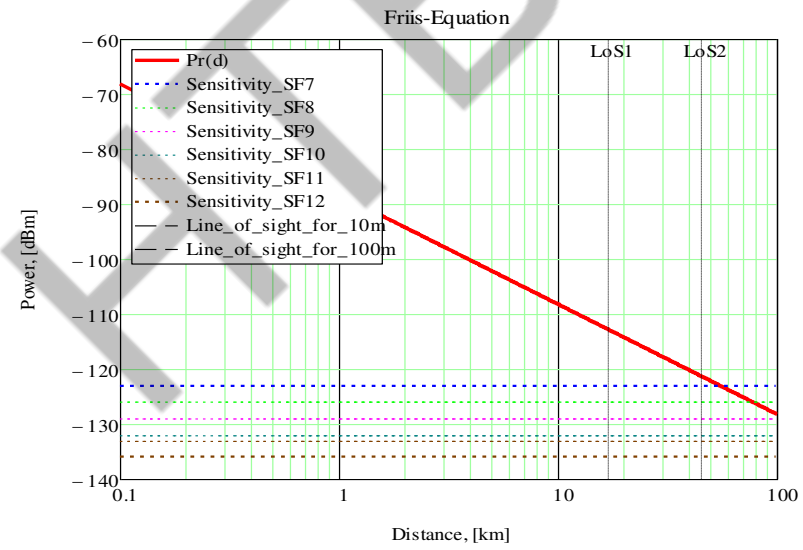

Fig. 11. Dependence of the LoRaWAN radio signal power at the receiver input on the distance to the transmitter (Fries model)

The maximum distance is about 120 km. The known record values for this time, obtained experimentally, are 741 km and 766 km, while the height of the transmitter was 33 km and 25 km, respectively [20]. In that experiment, LoRaWAN modules were launched on a balloon.

4.2.2 LoRaWAN radio signal attenuation in areas with interference

Well-known manufacturers of LPWAN radio modem chips, including the ISM range, such as STMicroelectronics: and Texas Instrument recommend also using a two-beam model to estimate the range of the communication channel [21, 22]. The two-beam model requires a line of sight between the receiver and transmitter antennas. Communication equipment usually operates near the surface of the earth. Therefore, to estimate the range, you also need to take into account the influence of the Earth (simplified form of the formula):

$$P_{2ray}(d) = \left(\frac{\lambda}{4\pi * d}\right)^2 * 4 * \left(\sin\left(\frac{(2*\pi*h_m*h_b)}{\lambda * d}\right)\right)^2 \quad (4.3)$$

The calculation results are shown in Fig. 4.5.

To compare the results, the line-of-sight (LoS) range, which takes into account the limitation of transmission due to the curvature of the earth's surface for a receiving antenna height of 10 meters and 100 meters (transmitter antenna height of 1 m), was also added to the calculations:

$$LoS_1 = 4.12\left(\sqrt{h_b} + \sqrt{h_m}\right) = 4.12\left(\sqrt{1} + \sqrt{10}\right) = 17 \text{ км}$$

$$LoS_2 = 4.12\left(\sqrt{h_b} + \sqrt{h_m}\right) = 4.12\left(\sqrt{1} + \sqrt{100}\right) = 45 \text{ км} \quad (4.4)$$

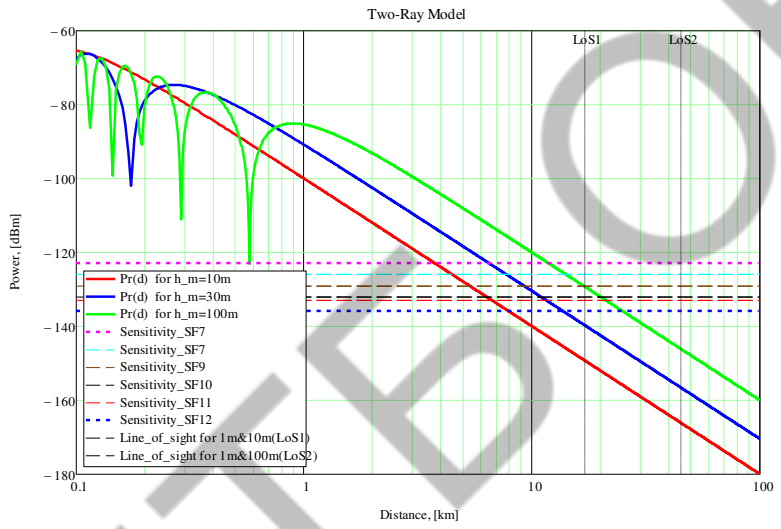

Fig. 12. Dependence of the LoRaWAN radio signal power at the receiver input on the distance to the transmitter (two-beam model)

From Fig. 12 it can be seen that for the selected heights of the antennas (1 m for the transmitting and 10...100 m for the receiving) the influence of wave interference disappears at distances greater than 1 km, so simplified expressions can be used. The maximum distance according to this model was 26 km (SF12, height of receiving antenna 100 m, transmitting antenna 1 m).

Next, the Hata model, which is also called the Okumura-Hata model [23], was chosen for evaluation. This model is used to predict radio wave propagation loss. The essence of the model is to estimate the propagation of radio waves based on the prediction of losses on the way of transmitting information in the propagation medium. The model is based on the use of the three-dimensional SBR (shooting and reflecting beam) algorithm, which is used to determine the paths of rays from the base station to the mobile station in three-dimensional space. Hut's model in the form of a mathematical notation is also based on Okumura's experimental data.

Formulas (4.5–4.7) are used to study the attenuation of the LoRaWAN radio signal in different areas (urban, suburban and rural):

$$L_{urban} = \begin{matrix} 65.99+26.16*\log(f_c)+(44.99-6.55*\log(h_b)*\log(d)-13.82*\log(h_b)-(3.2* \\ *\log(11.75*h_m)^2-4.97 \quad if \quad d \leq 20\ km \\ 65.99+26.16*\log(f_c)+(44.99-6.55*\log(h_b)*\log(d)^{b(d)}-13.82*\log(h_b)-(3.2* \\ *\log(11.75*h_m)^2-4.97 \quad if \quad d \geq 20\ km \end{matrix} \tag{4.5}$$

where: f_c - transmission frequency;

h_b–base station antenna height;

h_m - the height of the antenna of the mobile station;

d - distance between base and mobile stations.

$$L_{suburban} = \begin{matrix} L_{urban}-2*\left(\log\left(\frac{f_c}{28}\right)^2\right)-5.4 \quad if \quad d \leq 20\ km \\ L_{urban}-2*\left(\log\left(\frac{f_c}{28}\right)^2\right)-5.4 \quad if \quad d \geq 20\ km \end{matrix}, \tag{4.6}$$

$$L_{rural} = \begin{matrix} L_{suburban}-4.78*(\log(f_c)^2)+18*\log(f_c)\ if \quad d \leq 20\ km \\ L_{suburban}-4.78*(\log(f_c)^2)+18*\log(f_c)\ if \quad d \geq 20\ km \end{matrix}, \tag{4.7}$$

It should be noted that despite the fact that the Okumura-Hata model is a fairly widespread model for estimating the communication range, including for the LoRaWAN protocol [24], it has some limitations in application, in particular: standard indicators of the height of mobile stations in the Okumura-Hata model from 30 to 200 meters, which significantly reduces the adequacy of calculations for a base station below 30 meters and a mobile station above 200 meters, or requires additional experimental studies [25].

We use formula (4.8) to calculate the power at the receiver input:

$$Pr = ERP - L, \tag{4.8}$$

where ERP is the effective radiation power of the transmitter.

The results of the calculations are presented in Fig.13.

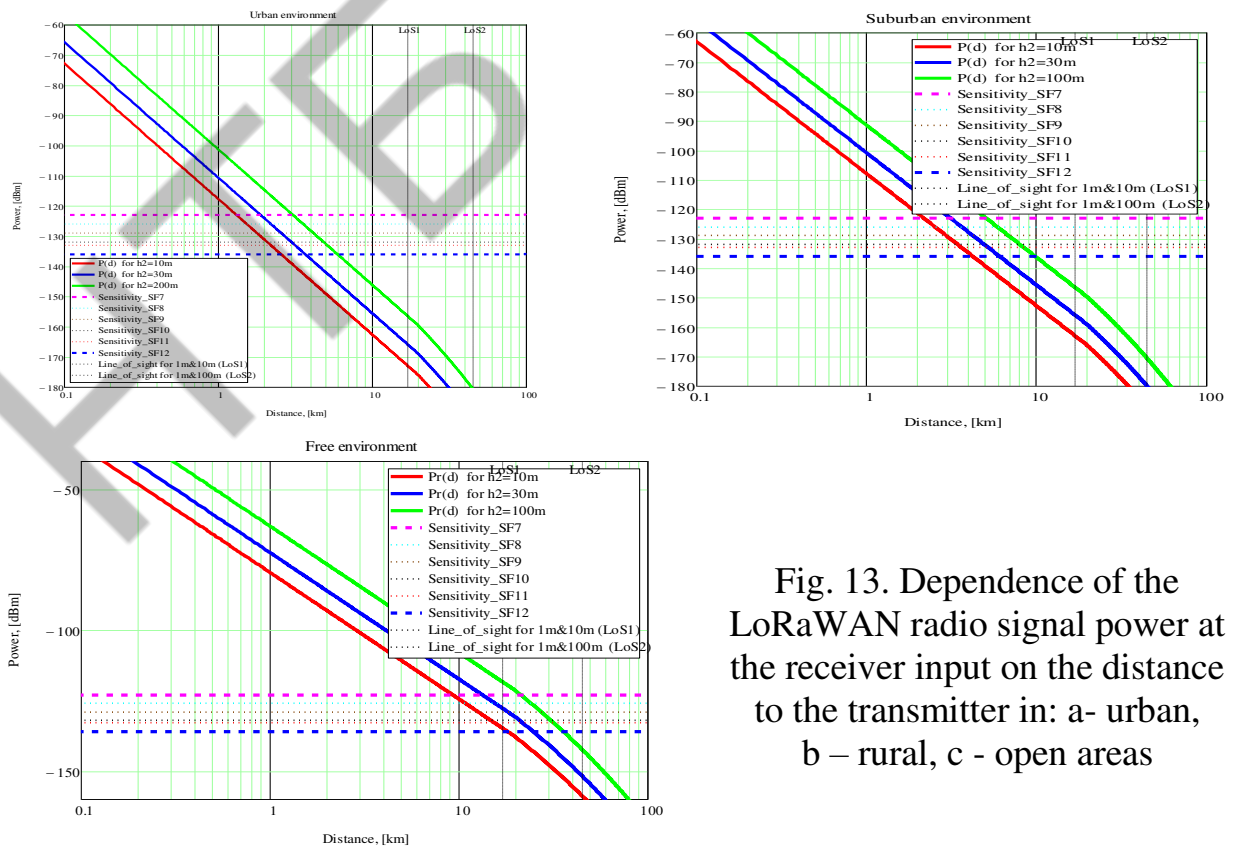

Fig. 13. Dependence of the LoRaWAN radio signal power at the receiver input on the distance to the transmitter in: a- urban, b – rural, c - open areas

It can be seen that when the line-of-sight range threshold is overcome (or near it), the angle of the curve changes, the signal begins to lose power more quickly. The maximum transmission range of the LoRaWAN signal in the open area of the Okumura-Hata model, for the heights of the receiving and transmitting antennas of 100 and 1 m, respectively, is 35 km. As can be seen from Fig. 11 and 13, the signal level at the receiver input calculated according to the Fries formula at a distance of about 5 km coincides with the values calculated according to the Hata-Okumura model for open terrain with relatively low values of the height of the transmitting antennas (1..3m), but the signal level at longer distances. The obtained results allow us to estimate the maximum distance to the ground base station, depending on the conditions and terrain - 30...40 km,

V.CONCLUSIONS

In the scientific work, the system of backup is proposed emergency communicate on built on the basis of LoRaWAN protocol. A detailed analysis of the organization of such a communication system and calculations revealed the strengths and weaknesses of such a system. In conditions of direct visibility and if available quadcopter slingshots, with the help of which the device for transmitting information can be lifted quite high into the air, LoRaWAN shows extremely good results in terms of transmission range.

To date, the following advantages of the developed system can be said:

- due to efficient energy consumption when transmitting small data packets, the energy consumption level of the end device is slightly around 1 year, for the case of transmitting 100 and receiving 100 messages per day;

-the maximum distance to the base station, depending on the conditions and terrain, is up to 300 km;

- to use the system, it is not necessary to obtain a frequency license and pay for the radio frequency spectrum;

- the construction of such a system is relatively cheap, compared to others with such a transmission range, due to the final cost of the device and the base station;

- with a sufficiently developed LoRaWAN infrastructure of base stations, high efficiency of receiving an alarm message by rescue services.

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4. POWER ENGINEERING AND ENERGY EFFICIENCY

ENERGY RECOVERY OF A HOUSEHOLD HEATING STOVE

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Abstract. *The use of stove heating is still widespread and economically justified in Ukrainian agriculture. Converting at least part of the energy emitted into the air by a household stove creates conditions for saving fuel resources, provides electricity to homes during interruptions in the central power supply, and can be a significant help for private households. The simulation of the process of generating electricity by recuperating the waste energy of a household stove was carried out in this research. The physical conditions for placing a thermoelectric generator (TEG) in the stove were analyzed. Based on the analysis results of the structure of household stoves features, a certain type of thermoelectric module was selected to simulate the operation of the TEG. Using OpenModelica software and Dymola graphic editor, simulation modeling of the main temperature parameters inside the stove was performed, and the TEG power was calculated. It has been found that during the heating period, as a result of the recovery of waste energy from a household heating stove, it can be possible to generate at least 66 kWh of electricity per month.*

Keywords: *energy recovery, thermoelectric generator, simulation modeling, household stove.*

I. INTRODUCTION

In modern conditions of a significant rise in the cost of energy, stove heating is very often used in rural areas and in suburban dachas of Ukraine. In stoves, biomass is typically burned for heat production, cooking and hot water. The efficiency of fuel combustion is quite low, taking into account the heat emitted through the pipe to the outside. Converting at least part of the waste energy of a household stove into electrical energy can cover the minimum rate of consumption of electrical energy in an individual building.

Thermoelectric conversion is a universal source of electrical energy. It allows the use of almost any source of heat flux, including those at small temperature differences, at which the use of other conversion methods is impossible. Recently, devices that utilize the energy of heat flows at a temperature difference of less than 10 K have received practical application. Until now, a significant limitation of its use is only a relatively low efficiency factor for converting heat flow into electrical energy. However, the thermoelectric conversion of at least a part of the waste energy of a household stove creates conditions for saving fuel resources, solving the problem of providing electrical energy during interruptions in the central power supply or increased load, and can be a significant help for households.

II. LITERATURE ANALYSIS

Waste energy from a household stove can be recovered using the thermoelectric (TE) effect, which makes it possible to obtain electricity from the heat flow. This process takes place using thermoelectric modules (TEM), which often referred to as Seebeck modules.

Recently, the possibility of recovering heat emitted outside by heating sources based on the use of thermoelectric generators (TEG) has been studied quite extensively. For example, authors describe [1] the development of a 50-watt thermoelectric generator aimed at recovering low-quality heat during cooling in industrial processes and in systems with highly active radioisotope sources. The possibility of connecting thermoelectric generators to wood-burning stoves was also discussed in the paper [2]. In laboratory experiments, it has been shown that during normal operation of the stove, an additional 28 W / h of electricity can be obtained. There are also a number of studies aimed at studying thermoelectric materials, finding the efficiency of functioning of heat exchange devices, analyzing various constructive models of thermoelectric generators (descriptions of their functioning and design) and ideas for increasing the efficiency of high-temperature TEM [3-5].

2.1. Efficiency of using TEG thermoelectric modules

According to the principle of operation, a thermoelectric generator is the same heat engine in which the working fluid is an electron gas of a semiconductor, which converts thermal energy into electrical energy. As in any heat engine, the TEG efficiency primarily depends on the efficiency of the Carnot cycle, so the design must have minimal heat losses during heat transfer in the semiconductor material and during heat removal from it. The main units of TEG are: heat source; thermopile with connecting and insulating layers; device for removing heat (refrigerator); a supporting construction that provides the necessary strength of the entire machine and the reliability of its operation.

Modern TEG have an efficiency of about 7% in the low temperature range (less than 350 °C) and 10% in the high temperature range (more than 350 °C). Such indicators have already ensured their application in various fields from microelectronics to energy. In the energy sector, due to their low efficiency, they are mainly used for the utilization of thermal residual energy. They increase the intensity of the selection of the emitted thermal energy into the "savings box" of the heating system.

In order to increase the electrical power produced, it is necessary to increase the heat flow through the heat exchanger, and as a result, the temperature on the TEM hot side also increases. The main difficulty in using TEG is the compromise between the heat flux through the modules and the acceptable temperature range for modern thermoelectric materials.

TEG will directly convert part of the thermal energy flowing through them into electricity. The main component of these devices is the Seebeck module or TEM (Fig. 1), which usually contains from several tens to hundreds of pairs of TEs connected electrically in series and thermally in parallel. However, other elements

surrounding this module are also necessary for the industrial use of the module: heat exchangers that enhance heat transfer through the modules, and electronic DC converters that regulate the output voltage.

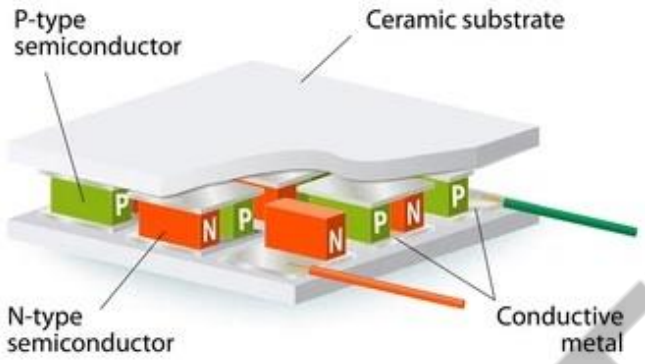

Fig. 1. A thermoelectric module [2]

The TEM efficiency (η_{TE}), which is the ratio of the electrical energy produced (W_{elec}) to the heat (Q_H) reaching the hot side of the module, is determined by the formula obtained under the assumption that the properties of the TEM material are constant [2]:

$$\eta_{TE} = \frac{W_{elec}}{Q_H} = \frac{\Delta T}{T_h} \times \frac{\frac{m}{m+1}}{1 + \frac{(m+1)}{zT_h} - \frac{\Delta T}{2T_h \times (m+1)}} \quad (1)$$

where T_h – temperature of the TEM hot side, K; T_c – temperature of the TEM cold side, K; $\Delta T = T_h - T_c$ – temperature difference, K; z – quality factor of the TEM material, m – ratio of the electrical load resistance to the internal resistance of the TEM. Maximum efficiency is achieved with the optimal m_{opt} ratio and is determined from:

$$\eta_{TE_{max}} = \frac{W_{elec}}{Q_H} = \frac{\Delta T}{T_h} \times \frac{\sqrt{1+zT} - 1}{\sqrt{1+zT} + \frac{T_c}{T_h}}$$

$$m_{opt} = \sqrt{1+zT}, \quad (2)$$

where T – average temperature, K.

According to the data [3], the expected efficiency of various values of the quality factor zT is shown in Figure 2. Current commercially available modules Bi_2Te_3 have a maximum efficiency score close to 1. There are also reports of quality scores higher than 2, but it will be a long time before such a module becomes commercially available [3]. Due to the fact that the quality index is not constant, but is a function of temperature, it would be more correct to take into account the average quality index. This average quality score ranges from 0.5 to 0.8 for commercially available modules. Modules produced by the American company Thermonamic have an efficiency of about 5% for a temperature difference of 270 K, which corresponds to an average value of $zT = 0.5$ [5].

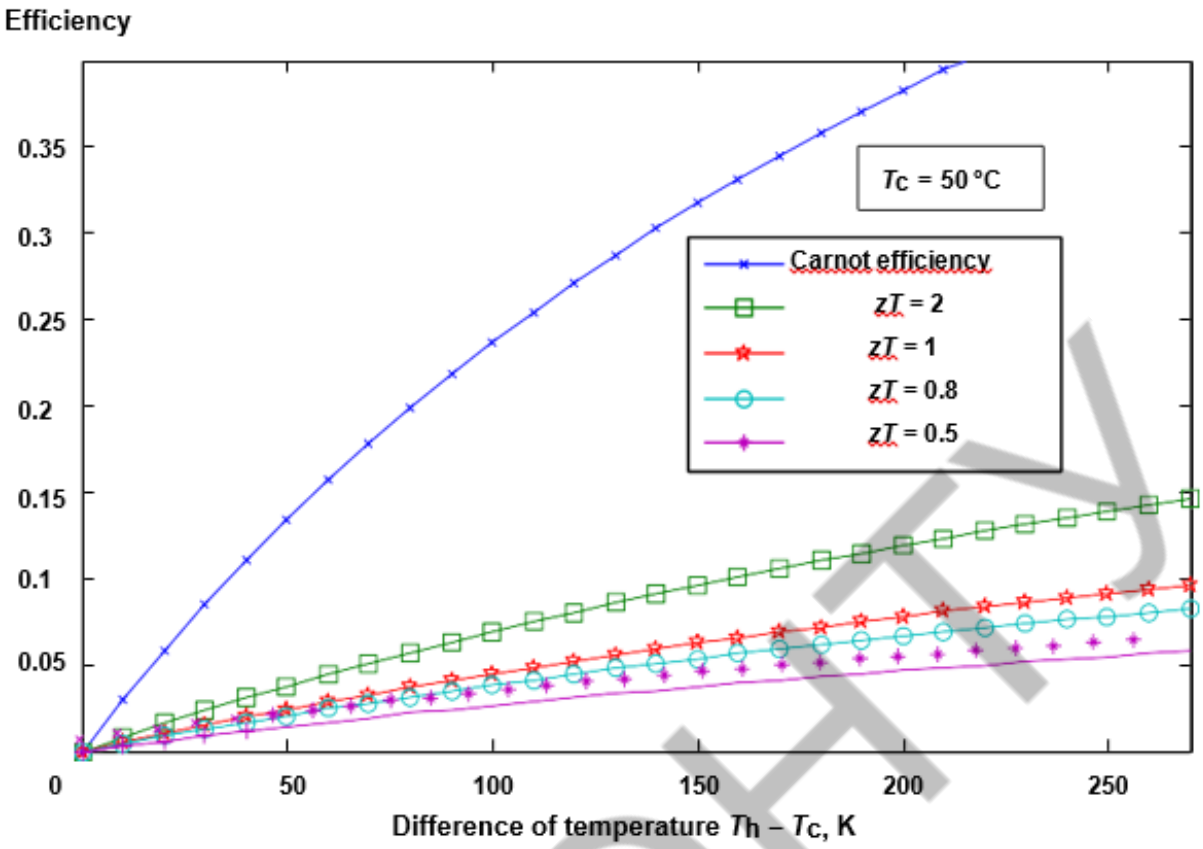

Fig. 2. Dependence of TEM efficiency on the temperature difference between hot and cold surfaces [3]

Figure 2 clearly shows the TEM efficiency, which is not very high. However, TEM have other advantages that largely offset their low efficiency. TEM have no moving parts, no working fluids, they are silent and maintenance free. For example, they have been used in space for many years [4, 6].

Thus, TEM are useful in such cases: use of a free source of energy such as the sun, heat recovery or use of a combined heat and power system with low levels of electricity production (<100 W). They are especially actively used in the automotive industry, where TEM is one of the possible solutions to improve efficiency by using heat from exhaust gases [7-10].

2.2. Connection of TEG to household stoves

There are a number of studies on the connection of TEG with modules based on Bi2Te3 to cooking stoves or heating stoves. Thus, the method of TEG connection was studied in papers [11, 12], when the exhaust gases were used as a source of heat, and the outside air in forced convection as a source of cold. The electrical power received was about 4W after the DC/DC controller. The operation of TEG using exhaust gases as a heat source and water circulation as a cold absorber was studied [13]. The power obtained using the Bi2Te3 module was about 10 W. But at the same time, the consumption of the pump was not taken into account and an electronic converter was not used to accumulate electricity.

O'Shaughnessy et al. [14] developed their own prototype electric generator for portable stoves (chitetezo mbaula stoves). Their goal was also to reduce the amount of fuel for the stove. TEG used a heat pipe to collect heat from the stove and a fan to cool the cold side of the TEM. From laboratory experiments, the maximum output power of the TEG was 5.9 W. On average, 3 W·h of energy entered the battery during a typical burn for one hour.

Another TEG model was provided for equipping stoves [15, 16]. This TEG had one TEM and produced a maximum electrical power of 9.5 W. However, due to losses in the DC/DC converter electronics, the original maximum power was 7.6 W. A special device using a gas heater was configured to synchronize with the temperature in the stove. A DC/DC converter with maximum power point tracking made it possible to generate a stable electrical energy voltage of 6 V, which was supplied to a 12 V lead-acid battery [17]. On average, during a 2-hour experiment using a TEG equipped with two TEM, 18 W·h of energy was stored in the battery (Bi_2Te_3 modules from Thermonamic). The authors also note that between 35 and 55 W·h of energy can be stored in the battery during a typical day, depending on the duration of two cooking sessions (in the case of a cooktop). These authors also modeled processes for a *cooking* stove in paper [18]. However, despite the fact that this experiment made it possible to evaluate the performance of the generator, the conditions of its testing do not fully correspond to those that take place in a stove. In addition, a complete simulation model of the use of the energy of the exhaust gases of a household *heating* stove with its conversion into electrical energy has not been considered so far.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The **object of the study** is the conversion of thermal energy into electrical energy using a thermoelectric generator in household conditions.

The **subject of the study** is the recovery of waste energy from a household stove.

The **aim of the study** is to model the process of generating electricity by recuperating the waste energy of a household heating stove.

To achieve the goal of the study, **research methods** were used: system analysis and synthesis, a functional-physical method of search design, which consists in setting and solving problems of technical creativity based on the use of heuristic techniques, analysis of the functions of technical systems and their elements, synthesis of chains of physical and technical effects to obtain new principles of information objects operation with the involvement of computer programs to perform such procedures.

IV. RESULTS. SIMULATION OF THE ENERGY RECOVERY PROCESS OF A HOUSEHOLD HEATING STOVE

4.1. Physical conditions for TEG placement

The physical processes in the stove are very multifactorial. Therefore, in general terms, it is difficult to theoretically determine the value of efficiency in the operating mode. The range of efficiency values of the stove ranges from 90% with low draft and decreases to 50% with strong ventilation of the furnace [19]. Therefore, in the study,

we will rely on the general calculated values of efficiency, regulated by the developers of stoves [20]. These values average 75% with optimal ventilation of the stove furnace.

For further calculations, we will choose the average rate of heat energy consumption for an individual house, which is 70 W/m^2. Consider a one-story individual building with an area of about 100 m^2. To ensure its heating, a thermal power is required according to the standards of 7.3 kW, and taking into account the consumption for ventilation – 7.5 kW. Taking into account the efficiency of the stove (75%), the power of this stove should be 10 kW. Heat losses in this case will be 2.5 kW [20].

In technical calculations of combustion, the following design composition of dry atmospheric air is taken: O_2 = 21% and N_2 = 79%. In addition, water vapor is added, which can decompose into components involved in the combustion process. The flue gases also contain combustion products. It is necessary to know the speed of the flue gas for its modeling. In order for the fuel to definitely burn in the stove, the actual air flow must exceed the theoretical value. The ratio of the actual air flow to the theoretical value is called the air flow coefficient *n*. For efficient stoves this coefficient should be *n* = 1.05-1.1. If the actual air consumption is less than the theoretical one, that is, n < 1, then incomplete combustion of the fuel takes place, called chemical underburning. For example, the value of the theoretical air flow for natural gas is 9-9.5.

A more universal indicator is the coefficient of emission of combustion products per unit of power. The amount of combustion products per unit of fuel combustion heat increases with an increase in fuel ballast in the form of nitrogen, carbon dioxide, and water vapor. Carbon monoxide has the lowest specific output of exhaust gases per 1 MJ of fuel combustion heat, which is V_{sp}= 0.227 m^3/MJ. For hydrogen V_{sp} = 0.268 m^3/MJ, for carbon V_{sp} = 0.26 m^3/MJ, for natural gas V_{sp} = 0.294 m^3/MJ. For firewood, depending on their quality (specific density, humidity, etc.), V_{sp} = 0.35–0.45 m^3/MJ. To obtain the specific volume of exhaust gases per unit of power, it is necessary to multiply V_{sp} by the theoretical value of air use. It is assumed that gas is used as fuel. Therefore, according to the average value of the theoretical air flow, we obtain the specific output of the exhaust gas is V_{sp} = 3 m^3/MJ.

Taking into account the previously selected stove power *W* = 10 kW, the exhaust gas outflow rate is: *V* = 0.030 m^3/s.

The cross section of the chimney recommended for the construction of the stove type under consideration is 20x20 cm^2 [21]. Therefore, the speed of gas movement is V_g = 0.75 m/s. Based on the found value, we can conclude that the gas flow is laminar.

The gas temperature in the furnace, depending on the type of wood used, can reach 1000 °C. The combustion temperature of coal under ideal conditions reaches 2100°C, but fuel is burned in a heating stove at a maximum of 1000°C [22]. Because of this, the firebox is made from materials that are resistant to high temperatures, such as refractory bricks. A heat exchanger is installed immediately behind the firebox. At the inlet to the heat exchanger, the temperature is already 700-750 °C. This place is the most optimal for TEG placement (Fig. 3).

This place is optimal in many respects. Firstly, it is not necessary to significantly change the configuration of the stove to accommodate the TEG. Secondly, the temperature is acceptable for the use of the most common thermoelectric modules.

Thirdly, in this case, the energy of the burned gas is sufficient to generate electrical energy for the needs of the house.

Thus, during further calculations of the thermoelectric generator, the temperature of the inlet gases is T_h = 750 °C, and it is the temperature that set the value of T_1.

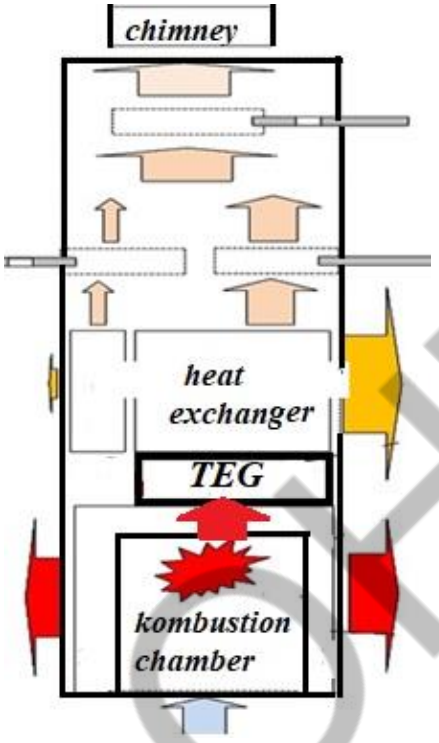

Fig. 3. Location of the thermoelectric generator

4.2. Choice of thermoelectric module for TEG

The next step is to select the type of TEM for the generator. An important parameter is the output electrical power. The maximum electric power according to the standard model is defined as [18]:

$$W_{\max} = F \times n\left(\frac{\alpha^2}{2\rho}\right)\left(\frac{A}{l}\right)(T_h - T_c) \quad (3)$$

where n – number of thermocouples on the TEM, α – Seebeck coefficient, ρ – electrical resistivity of the thermocouple, A – area of the thermocouple, l – length of the thermocouple. F – TEM manufacturing quality factor. To increase power, it is necessary to increase the temperature difference; however, T_h is limited by the maximum temperature allowed by the TEM use.

In accordance with the scheme of the thermoelectric generator element (Fig. 4), heat Q_1 is supplied to the TEG through the heater wall 1. Energy Q_2 is removed from the TEG through the cooler wall 7 (by radiation, convection). Junctions of semiconductor crystalline thermopillars 4, 9 are formed by metal busbars 3, 5, 8, which are electrically isolated from walls 1, 7 by dielectric layers 2, 6, operating on the basis of temperature difference $\Delta T = T_1 - T_2$.

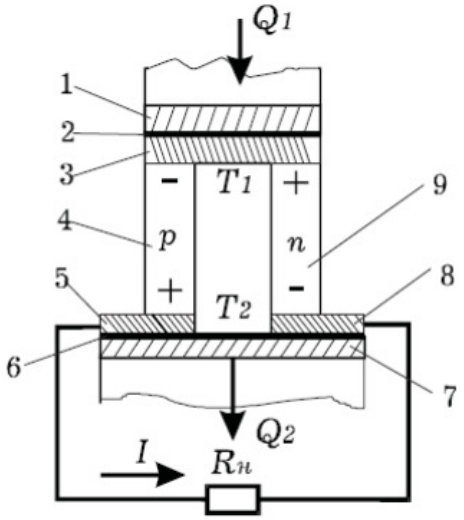

Fig. 4. Thermoelectric generator element

On the external load R_H of the TEG, a voltage is created equal to the thermo-EMF, except for the decrease in voltage on the internal resistance of the generator:

$$U = \mathrm{E} - I \cdot R \quad \text{or} \quad I \cdot \mathrm{R}_H = \mathrm{E} - I \cdot R$$

The current strength in the circuit is determined by the expression:

$$I = \frac{2 \cdot N \cdot \alpha \cdot \Delta T}{R + R_H} = \frac{2 \cdot N \cdot \alpha \cdot \Delta T}{R(1+m)}, \tag{4}$$

where $m = R_H/R$.

The load voltage is:

$$U = I \times R_H = 2N \cdot \alpha \cdot \Delta T \frac{m}{1+m}. \tag{5}$$

The power delivered to the outer circle can be calculated using the following formula:

$$P = I \times U = \frac{(2N \cdot \alpha)^2 \cdot \Delta T}{R} \times \frac{m}{(1+m)^2}. \tag{6}$$

The efficiency of the thermoelectric generator is estimated by the efficiency factor: $\eta = P/Q_h$.

For more efficient operation of the TEM, it is necessary to ensure the maximum allowable temperature difference between the sides of the module; for this, heat must be supplied to one of its sides (Q_1), and on the other, an effective removal of thermal energy (Q_2) must be ensured. The electrical power at the load is directly proportional to the square of the temperature difference ΔT: $P = Q_1\text{-}Q_2 = I^2R_H \sim \Delta T^2$.

To achieve maximum power, the value of the electrical resistance of the load must be equal to the value of the internal resistance of the generator module under operating conditions. By choosing the parameter m in a certain way, it is possible to change the efficiency, while the electric power that can be obtained from the thermoelectric generator will change (Fig. 5).

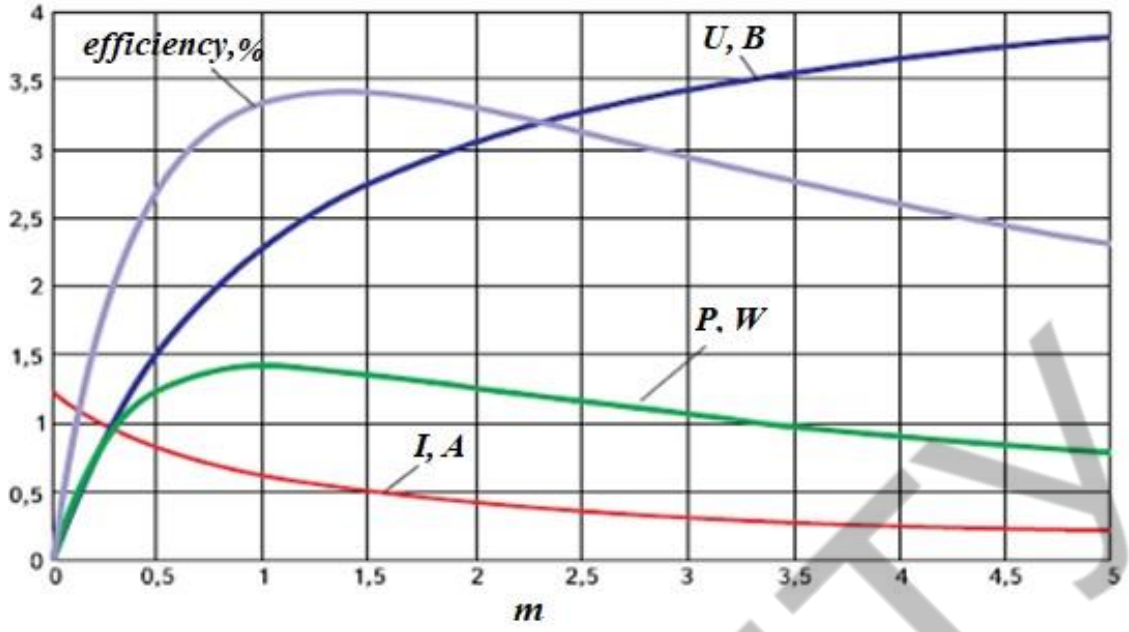

Fig. 5. Dependences of TEM characteristics on the parameter *m* [23]

The maximum power with TEG can be obtained when the external and internal loads are equal ($m = 1$), and the maximum efficiency is achieved at $m \approx 1.3$-1.4. Based on this, an adjustable load resistance is necessary depending on the converter current.

All TEG are conditionally divided into high temperature (above 350 °C), medium temperature (from 250 °C to 350 °C) and low temperature (up to 250 °C) converters. In accordance with the purpose of our research on the basis of a thermoelectric converter, it is supposed to use high-temperature converters. In Ukraine, such modules are serially produced as two-stage modules based on the Bi_2Te_3 – *Si-Ge* material. These are Altec-1023 and Altec-1024 modules. A diagram-drawing of the corresponding cascade module for hot side temperatures at the level of 750÷800 °C is shown in Figure 6.

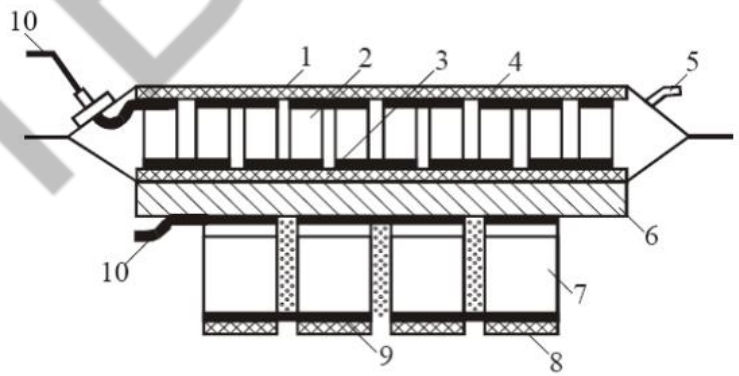

Fig. 6. Scheme of a two-stage thermoelectric module (Bi_2Te_3 – *Si-Ge*):
1 – sealed housing; 2 – thermoelements of the low-temperature cascade;
3 – electrical insulation; 4, 8 – ceramic plate; 5 – tubulation; 6 – heat transfer;
7 – thermoelements of the high-temperature cascade; 9 – switching plate;
10 – electric ports

The high-temperature cascade of the module is made of *Si-Ge*-based material, and the low-temperature cascade is made of Bi_2Te_3-based material. The low-temperature thermopile is sealed in a metal case, the free volume of which is filled with

an inert gas. Both stages are connected in series thermally and electrically. The module consists of two stages connected electrically and thermally in series. Each stage consists of thermocouples connected electrically in series and thermally connected in parallel.

Characteristics of a two-stage module based on $Bi_2Te_3 – Si\text{-}Ge$ are shown in Figure 7. According to the manufacturer's passport data, the maximum efficiency of the cascade module for T_h = 750 °C, T_c = 50 °C and interstage temperature T_{is} = 300 °C is 10.1%, the electrical power is 31 W, and the voltage at the matched load is 2.2 V [24]. As already noted, two TEM meet the requirements in the commercial market of Ukraine: Altek-1023 and Altek-1024. The module Altek-1024 has a greater value for the maximum allowable operating temperature. Therefore, the Altec-1024 module is selected for further modeling. They have a fairly high conversion efficiency, which is 10%.

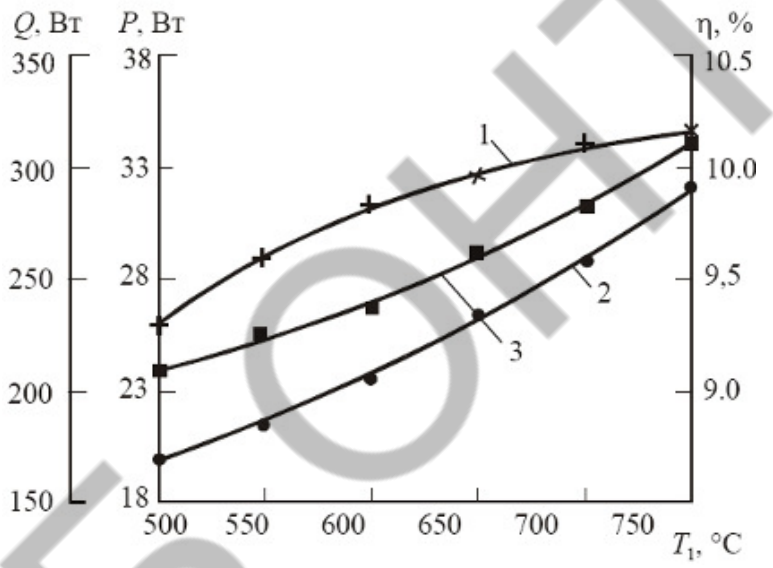

Fig. 7. Dependences of the two-stage module efficiency ($Bi_2Te_3 – Si\text{-}Ge$) η (3), electric power P (1), heat flow Q (2) on the hot side temperature [23]

The module has increased mechanical resistance due to the use of a special heat-conducting spacer between the high-temperature and low-temperature cascades. The module parameters are given in Table 1 [25].

Table 1. Altec-1024 thermoelectric module parameters [25]

T_h = 750 °C, T_c = 50 °C				**Dimensions, mm**				
I_{max}, A	U_{max}, V	W_{max}, W	η, %	Length l, mm	Width w, mm	Height e, mm	Hot side, mm	Cold side, mm
14.5	2.2	31	10.1	106	106	23	50x55	60x60

Unfortunately, the thermal resistance of the module is not given in the passport data. To determine it, the data of dependencies shown in Figures 5, 7 were used. The thermal power passing through the module is defined as:

$$\Phi = W_{max}/\eta = 306{,}9 \approx 300\ W. \quad (7)$$

Then the maximum thermal resistance is equal to:

$$R_T = \Phi / \Delta T_{\max} = 300 / (750 - 50) = 0.43 \ \text{Ohm/K}. \quad (8)$$

At the maximum temperature T_{max}, the thermal conductivity of the module λ is equal to:

$$\lambda = \frac{\Phi \cdot e}{\Delta T_{\max} \cdot l \cdot w} = 0.877 \ \text{V/(m} \cdot \text{K)}.$$

4.3. Simulation of generator operation

Modeling was carried out in the OpenModelica program using the Dymola graphic editor [26]. To simulate the operation of the TEG, we proceeded from the following. Based on the size of the considered Altek 1024 modules (100 mm × 100 mm) and taking into account the typical size of the furnace pipe, it is suggested to install 2 rows of modules, each of which contains 4 TEMs.Altec-1024 modules in the amount of 8 pieces are installed in the stove as shown in Figure 8. Heat is supplied from the bottom up.

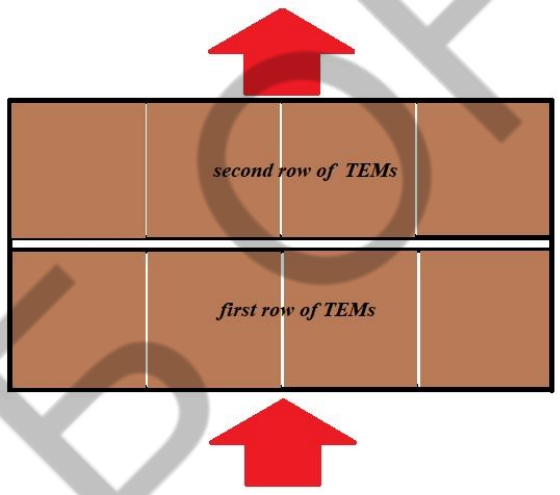

Fig. 8. Location of TEMs in the stove

The temperature of the flame after heating the stove varies from 800 to 1000 °C. The temperature on the hot side of the first row of modules can be permanently 750 °C (with short-term changes). The cold wall temperature is 50 °C. It should be noted that it must be less than 200 °C in total.

In the software system, imitation temperature sensors were placed in different places of the stove. The simulation temperature sensor T_1 corresponded to the measurement of the temperature of the hot gas entering the TEG, the sensor T_0 was responsible for determining the gas temperature at the TEG outlet. Finally, the T_2 sensor provided information about the wall temperature and the corresponding cold side temperature of the module. The error of the simulated temperature reading was 0.5 °C. The overall error of computer data processing did not exceed 0.021%.

Figure 9 shows the results of a simulation experiment lasting 2 hours (with a step of 1 minute) to simulate the main temperature parameters inside the stove. The entire

time of the experiment can be divided into three parts: the first 15 minutes – heating the stove; from 15 to 75 minutes – a period of stable burning; from 75 to 120 minutes – the attenuation of the combustion process and the cooling of the stove.

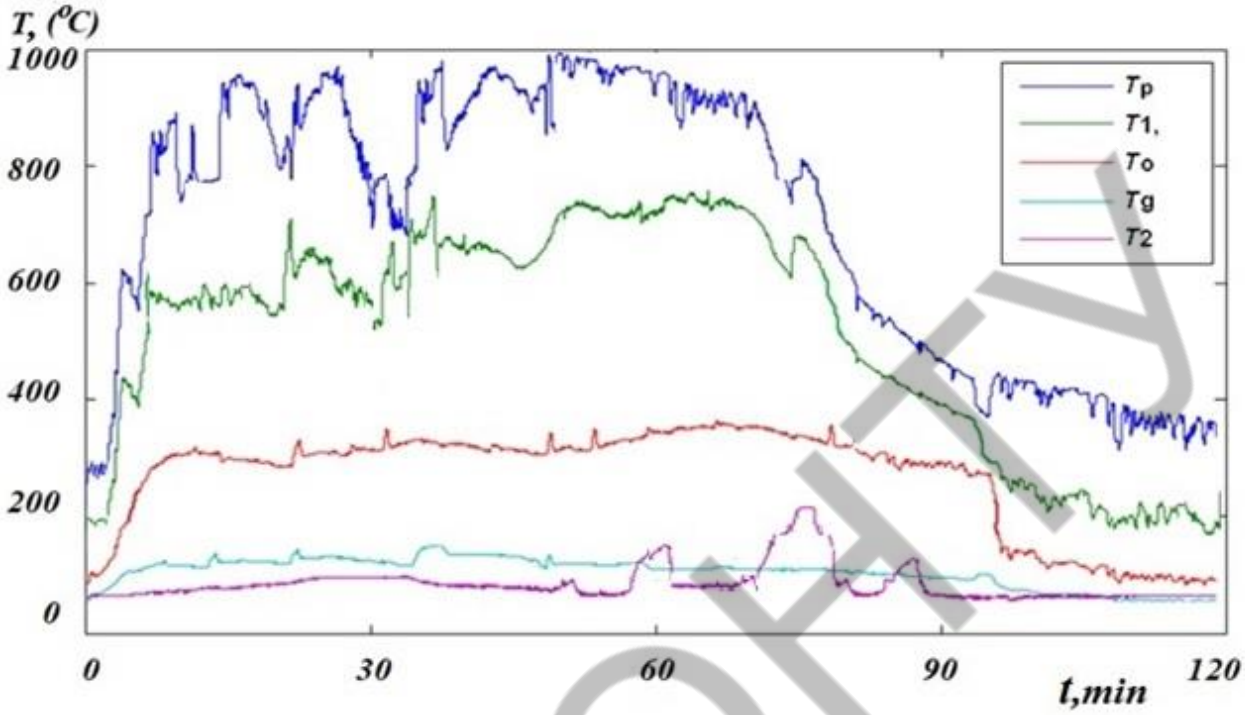

Fig. 9. Simulation of the main temperature parameters inside a household stove T_p – temperature in the upper part of the flame chamber; T_g – flue gas temperature at the stove outlet; T_1 and T_0 – temperature at the inlet and outlet of the heat exchanger; T_2 – cold wall temperature

It can be seen from the figure 9 that the model takes into account the temperature irregularity that develops when fuel is loaded. Most of the time, the simulated temperature in the upper part of the flame chamber (T_p) was about 800 °C with irregular programmed fluctuations (corresponding to changes in the amount of fuel burned in a given time interval). As a result, the flue gas temperature at the stove outlet (T_g) through the generator was about 300–320 °C. The temperature at the cold chimney wall T_c was about 50 °C. The difference in temperature ($\Delta T = T_1$-T_0) of the hot gas along the heat exchanger ranges from 400 to 500 °C. During combustion, an increase in the cold wall temperature T_2 was modulated and three peaks of this temperature can be observed.

Knowing the temperature of the hot and cold sides and the properties of the TEM, a calculation was made (within a linear approximation) of the amount of energy produced. It should be noted that in the top row, the sections will have an inlet gas temperature equal to the outlet from the first section. Table 2 shows the average power produced by each TEM according to its location.

Table 2. Characteristics of TEM

TEM location	Upper	Lower	Amount
Power, W	16.3	29.6	45.9

It should be noted that the voltage at the output of the thermoelectric generator, depending on the fluctuations of the thermal energy passing through it (the initial temperature of the exhaust gases), will constantly change. Based on a sufficiently low output voltage, it is proposed to connect the outputs from all modules electrically in series and connect to the battery to accumulate an electric charge. Since 4 pairs of modules are used, the resulting energy must be multiplied by four. That is, the TEG power is 183.6 W.

If during the heating season the stove will operate on average 12 hours a day, then at least 66 kWh of electricity per month can be obtained.

The result obtained is very encouraging, as it shows that it is possible to count on sufficient additional power supply for the building. However, to verify the simulation results, it is necessary to conduct a series of experimental studies with a real household heating stove.

V. CONCLUSIONS

1. According to the results of the analysis of scientific and technical literature on the recovery of exhaust gases from a household stove, it was found that:

– recovery of waste energy of a household stove can be carried out due to the thermoelectric effect, which makes it possible to obtain electricity from a heat flow using a TEG;

– modern TEG in the high-temperature range (from 350 to 750°C) have an efficiency of about 10%;

– a complete simulation model of the use of the energy of the exhaust gases of a household heating stove with its conversion into electrical energy has not been considered so far.

2. Basic input data for simulation modeling:

– furnace type of stove with a power of 10 kW, the efficiency of which is 75%;

– the optimal position for placing the TEG, which is located behind the furnace at the inlet of the heat exchanger, where the gas temperature is about 750 °C;

– two-stage thermoelectric modules Altec 1024 based on the material Bi_2Te_3 – *Si-Ge*, having the appropriate operating temperature.

3. Using OpenModelica software and Dymola graphic editor, simulation modeling of the main temperature parameters inside the stove was performed, and the calculated power of the TEG is 183.6 W. It has been found that during the heating period, as a result of the recovery of waste energy from a household heating stove, it can be possible to generate at least 66 kWh of electricity per month. This energy is sufficient to meet the minimum needs of the household during interruptions in the central power supply.

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DEVELOPMENT OF A METHODOLOGY FOR INCREASING THE EFFICIENCY OF A WIND TURBINE

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Abstract. *Increasing the independence of its own energy system is of particular importance for ensuring the stable development of Ukraine. In Ukraine's conditions, this means reducing dependence on fuel imports, which in turn will have a positive effect on Ukraine's balance of payments, increasing its security and competitiveness in the international arena. Equally important is the issue of identifying the own potential of renewable energy and its effective use in the economy. The paper analyzes wind power potentials.*

All these factors compensate the population and the state for the attractive tariff for electricity production from renewable energy sources (RES) for investors. It should be noted that today wind power competes with nuclear power in many countries. This is explained by the fact that the necessary costs for improving safety, reducing the risk of possible, even minor impacts on public health and environmental pollution, as well as insurance policies make the cost of electricity produced at NPPs high.

The purpose of the work: to research and develop a methodology for choosing a wind turbine based on the assessment of the produced specific energy of the wind flow of the selected area;

Key words: *WPP, wind turbine power, wind turbine moment, turning moment coefficient, wind speed.*

I. INTRODUCTION

Increasing the independence of its own energy system is of particular importance for ensuring the stable development of Ukraine. In Ukraine's conditions, this means reducing dependence on fuel imports, which in turn will have a positive effect on Ukraine's balance of payments, increasing its security and competitiveness on the international stage.

Equally important is the issue of identifying the own potential of renewable energy and its effective use in the economy. The paper analyzes the wind power potentials.

Positive factors that can offer the development of alternative energy in Armenia:
- ecologically clean and safe production of electricity;
- generating stations distributed over the territory;
- energy independent of imported fuel and international prices;
- no need to use water (for example, for reactor cooling systems) during electricity production;
- energy security and diversification of generating capacities.

All these factors compensate the population and the state for the attractive tariff for electricity production from renewable energy sources (RES) for investors.

It should be noted that today wind energy in many countries competes with nuclear energy. This is explained by the fact that the necessary costs for improving safety, reducing

the risk of possible, even minor impacts on public health and environmental pollution, as well as insurance policies make the cost of electricity produced at NPPs high.

II. LITERATURE ANALYSIS

1. Research of the method of selecting a wind installation

Let's consider the Raduga 1 wind turbine for this area as the distributed power of the wind flow over the entire height of the windmill and determine the possibility of increasing the efficiency of the wind turbine with a special system for adjusting the angles of installation of wind turbine blade blades.

All calculations will be carried out for the "Raduga 1" WPP, as the largest volume of available and necessary technical data is published in [1-4].

Currently, one wind turbine unit "Raduga 1" has been built, created with an asynchronous synchronous generator and with the possibility of adjusting the installation angle φ of the blades with the possibility of a special hydraulic drive. This ensured the operation of the wind turbine both in the mode with constant speed (z = const), and in the modes with a constant speed of rotation (nVK = const) of the wind turbine and constant power (PVEU = const). Such a system for adjusting the angle of installation φ of the blades provides, due to the specified adjustment, both self-starting and stopping of the turbine at a wind speed higher than the maximum permissible speed for wind turbines (25m/s).

The selection of wind turbines for this area is created in the following sequence:

1. We will estimate the resources of the wind potential of this area by statistical processing of a multi-year time series of wind speed values $V_0^{k=10}$, for example, from the "Ukrainian Hydrometeorological Center" [3] at the vane height h = 10m from the ground surface.

2. Recalculation of wind speed from the height of the axis of rotation, for example, a windmill (tower) $V_0^{k=10}$ Wind power generation is carried out according to a well-known formula:

$$V_0^{k=10} = \mathrm{V}_0^{\mathrm{h}=10} \cdot \left(\frac{h}{h_{10}} \right)^m , \qquad (1)$$

where $m = 0{,}2$.

The height to the axis of rotation of the windmill of the wind turbine is 38 m, the radius of the windmill.

3. By converting the wind speed data to the height of the wind turbine, repeatability curves are calculated, for example, according to the Grynevich formula:

$$t(V) = 1.038 \cdot \frac{\Delta V}{V_{cp}} \cdot \left(\frac{V}{V_{cp}} \right)^{0.5} \cdot e^{-0.547 \cdot \left[\frac{V}{V_{cp}} \right]^2} \cdot 100, \qquad (2)$$

where V – current value of wind speed, m/s; V_a – average long-term wind speed, m/s; ΔV-calculation step (for example, 1m).

Repeatability curve graph $t = f(V)$ wind speed according to (2) in fig. 1.

4. There is also a graph of the known [4,5] dependence of specific annual energy $E_{уд} = f(V)$ per square meter of the area orthogonal to the wind flow, determined by the formula:

$$E_{уд} = \frac{\rho}{2}\sum_{i=1}^{i=25} V_i^3 \cdot t_i \cdot (V_i) \cdot 8760 = \sum_{i=1}^{i=25} P_{0i} \cdot t_i \cdot (V_i) \cdot 8760, \frac{Вт \cdot ч}{м^2 \cdot год}, \quad (3)$$

where ρ – specific gravity of air; P_{0i} – specific power of a calm wind flow at the ith interval of wind speed gradation.

5. We are interested in formula (3) of the equation equal to $P_{уд} = f(V) = P_{0i} \cdot t_i(V_i), \frac{Вт}{м^2}$, the maximum of the characteristic coincides with the maximum of the characteristic $E_{уд} = f(V)$. According to the graph, it is reached at a wind speed of 13 m/s.

6. In fig. 1 graph of $P_{ВЕУ} = f(V)$ capacity of wind turbine "Raduga 1", from [2,6].

7. From fig. 1 shows that the wind speed of the nominal mode practically coincides with the wind speed of the maximum characteristic $E_{уд} = f(V)$, which testifies to the correctness of choosing a wind turbine for this area. In reality, the closer the original part of the characteristic is $P_{ВЕУ} = f(V)$ to the power characteristic of an ideal windmill, it is determined by the formula:

$$P_{ид} = \frac{\rho}{2} \cdot S \cdot V^2 \cdot C_p^{\max}, \quad (4)$$

where S – the area of the windmill, $C_p^{\max} = 16/27$ – power factor of an ideal windmill (criterion Zhukovskoho-Bettsa).

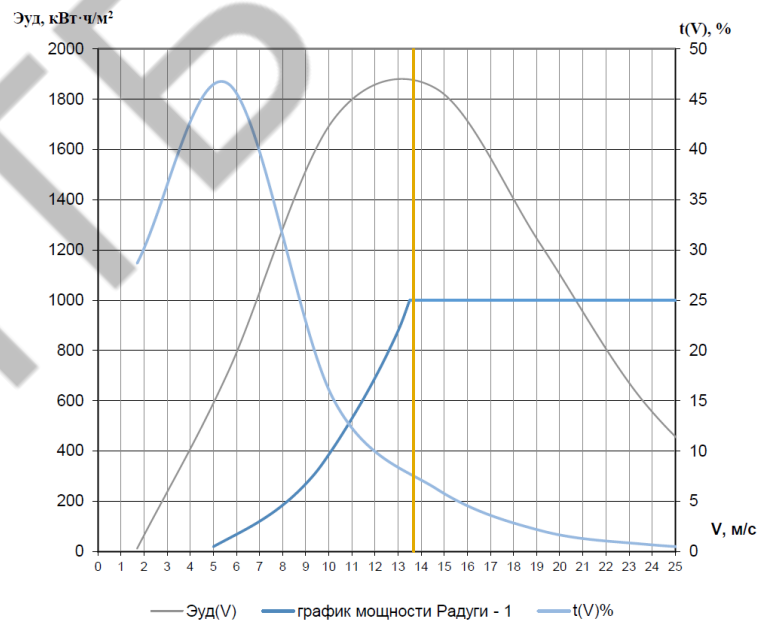

Fig. 1. Probable distribution of wind speed, specific wind energy potential of the wind flow at the height of the axis of rotation of the wind turbine wind turbine and power characteristics of the wind turbine "Raduga-1"

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

Relevance of work. Increasing the independence of its own energy system is of particular importance for ensuring the stable development of Ukraine. In Ukraine's conditions, this means reducing dependence on fuel imports, which in turn will have a positive effect on Ukraine's balance of payments, increasing its security and competitiveness in the international arena. Equally important is the issue of identifying the own potential of renewable energy and its effective use in the economy. The paper analyzes wind power potentials.

All these factors compensate the population and the state for the attractive tariff for electricity production from renewable energy sources (RES) for investors. It should be noted that today wind power competes with nuclear power in many countries. This is explained by the fact that the necessary costs for improving safety, reducing the risk of possible, even minor impacts on public health and environmental pollution, as well as insurance policies make the cost of electricity produced at NPPs high.

The purpose of the work: to research and develop a methodology for choosing a wind turbine based on the assessment of the produced specific energy of the wind flow of the selected area;

The object of the study: wind power plant "Raduga".

The subject of the study: characteristics of capacities and moments of the windmill; characteristics of the power produced by wind turbines.

IV. RESULTS

2. Increasing the efficiency of the wind energy installation

2.1. Technical data of wind turbine "Raduga-1"

Wind power installations "Raduga - 1" are intended:

- for the production of electrical energy as part of wind power stations or independently for general energy systems or separate energy nodes;
- autonomous operation on the load during parallel operation with other wind turbines as part of wind power stations without connection to the power system.

Wind energy installations are equipped with systems that ensure convenient, efficient and safe operation.

WPP - propeller type with a horizontal axis of rotation, with a three-bladed wind wheel equipped with fully rotating blades.

As a generator, an asynchronous synchronous generator is used with rotor power from a thyristor frequency converter.

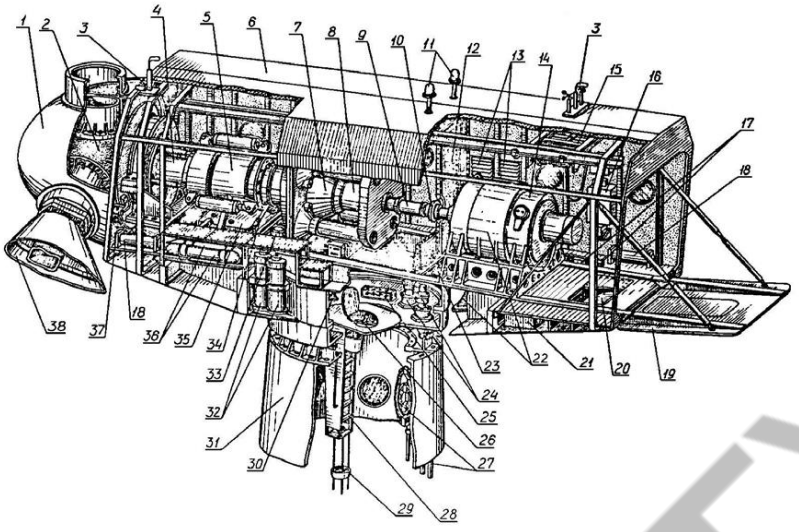

Fig. 2. Wind power plant "Raduga - 1": 1 - fairing; 2 - hub of the windmill; 3 - block of the system for measuring wind parameters; 4 - low-speed shaft; 5 - blade rotation mechanism; 6 - gondola; 7 - multiplier; 8 – circuit breaker; 9 - connecting shaft; 10 - compensation and safety clutch; 11 - blocking lights; 12 - insulating partition; 13 - louvers for air entering the nacelle; 14 - generator of asynchrony; 15 - crane device; 16 - control system units; 17 - blocks of electrical equipment; 18 - electric heater; 19 - folding platform; 20 - cargo hatch; 21 - block of the control system of the support-turning device; 22 - casing and duct for air removal from the generator; 23 - fire extinguisher; 24 - drive modules of the support-turning device; 25 - hydro remote control; 26 - brake; 27 - refueling pipelines and hoses; 28 - stairs; 29 - cable suspension device; 30 - electrohydraulic stopper; 32 - tower; 32 - pneumohydraulic accumulators; 33 - pump unit; 34 - brake stopper; 35 - oil tank; 36 - cylinders for emergency flapping of blades; 37 - brake; 38 - blade.

2.2. Increasing the efficiency of the wind turbine "Raduga - 1"

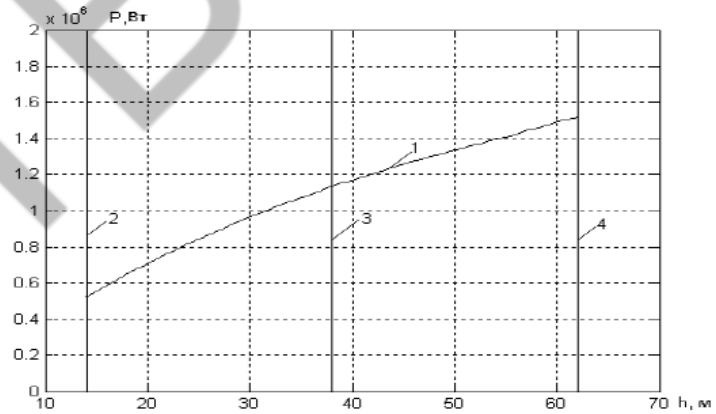

Fig. 3. Graph of the power developed by the wind flow taking into account the aerodynamic characteristics of the windmill by its height - 1; vertical lines 2, 3, 4 - respectively, the height of the lower limit (14 m), the axis of rotation (38 m) and the upper limit of the windmill (62 m)

The windmill model is represented by formulas [3,13]:

• speed:

$$z = \frac{n \cdot \pi \cdot R}{30 \cdot V}, \quad (5)$$

where n - speed of rotation of the windmill, rev/min; R – radius of the windmill, m;

• power factor of the windmill [7,8]:

$$C_p = z \cdot C_M, \quad (6)$$

where C_M - torque coefficient of the windmill;

• windmill power:

$$P = 0.5 \cdot \rho \cdot \pi \cdot R^2 \cdot V^3 \cdot C_p, \quad (7)$$

• torque of the windmill:

$$M = \frac{30 \cdot P}{\pi \cdot n}, \quad (8)$$

Since the wind speed over the height of the windmill is distributed significantly unevenly (see appendix), the power of the wind flow will also be unevenly distributed over the height of the windmill, fig. 3).

Equations (5) - (8) are implemented in the "Matlab Simulink" programming system in the form of a block diagram presented in Fig. 4 and the obtained characteristics of power and torque of wind turbine "Raduga-1" as a function of wind speed are presented in fig. 5 and 6.

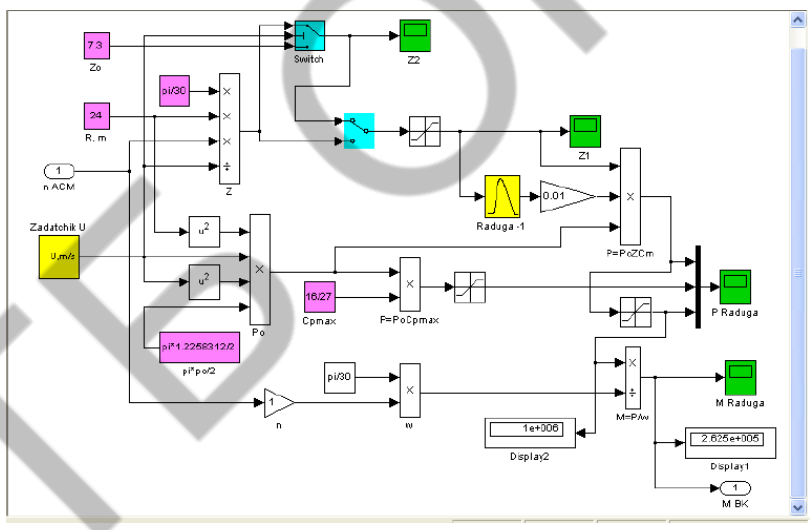

Fig. 4. Equations (5) - (7) implemented in the “Matlab Simulink” programming system in the form of a block diagram

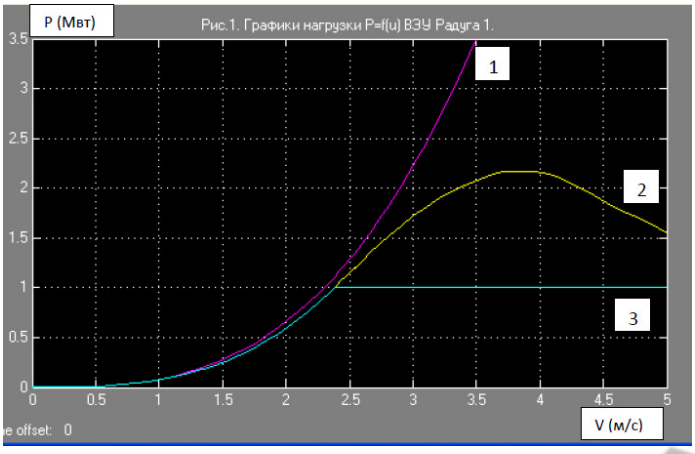

Fig. 5. Characteristics of wind turbine capacities as a function of wind speed: 1 - with an ideal wind turbine; 2 - at the "Raduga - 1" windmill; 3 - real characteristics of wind power plant "Raduga - 1" (speed scale 1:5)

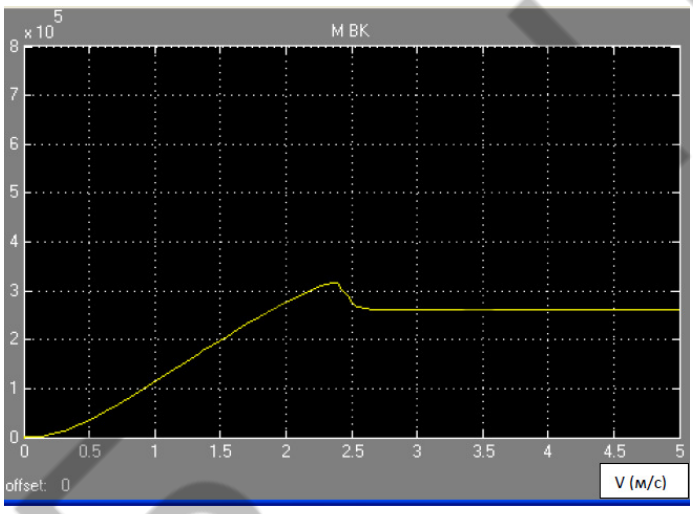

Fig. 6. Characteristics of the wind turbine moment "Raduga - 1" as a function of wind speed (scale of wind speed 1:5)

To construct a graph of real power distribution, let's divide the area of the windmill by its height into segments. The area of each i-th segment is determined by the formula [9]:

$$S_i = R^2 \cdot \left(\frac{\pi \cdot \alpha_i}{360^0} - 0.5 \cdot \sin \alpha_i \right), \quad (9)$$

where $0 \le \alpha_i \le 360^0$ - the current value of the angle of the i-th component (the calculation is carried out in steps of 1 degree).

Next, we define elementary areas [10]:

$$\Delta S_i = S_{i+1} - S_i, \quad (10)$$

Obviously, the condition [11] must be fulfilled:

$$\sum_{i=0}^{i=360} \Delta S_i = \pi \cdot R^2 = S_{BK}, \quad (11)$$

where S_{BK} - the area blown by the windmill. For each elementary area, using equations (5) - (7), we calculate, taking into account (1) the height of the windmill of elementary power [12]:

$$\Delta P_i = \Delta S_i - P_i(h), \quad (12)$$

where $P_i(h)$ - power values according to the graph of fig. 6.

The graph of elementary capacities $\Delta P_i = f(h)$ by the height of the windmill is presented in fig. 7 (see appendix). From the graph of Fig. 7, it can be seen that during the rotation of the windmill, its blades in the position above the axis of rotation are overloaded compared to the lower position. According to fig. 7 overload is 16.6%. Let's consider, as mentioned above, the possibility of using a system for adjusting the angle of installation of the blades of the windmill to increase the efficiency of wind turbines. For this, a family of graphs of turning moment coefficients from speed Z at different angles φ of the installation of the blades of the windmill is used, presented in Fig. 8.

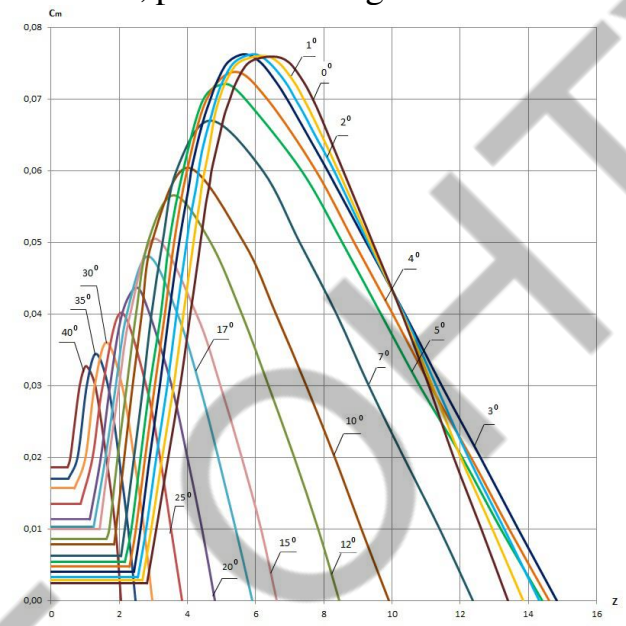

Fig. 8. Dependence of the turning moment coefficient on the speed $C_M = f(Z, \varphi)$ at different angles φ of the windmill blade installation

In relation to the characteristics according to equations (5) - (7), the characteristics of the power of the wind turbine as a function of the wind speed V at different angles φ were calculated and plotted for the three-blade wind turbine "Raduga 1" at the nominal rotation speed (n = 38 rpm) installation of blades (Fig. 9).

These characteristics are valid for simultaneous and joint adjustment of the installation angle φ common to all blades of the windmill. It can be seen from the family of wind power characteristics that if, for example, you draw a horizontal line at kW, then this mode can be ensured by the traditional method, namely by increasing the installation angle φ, common to all blades of the wind wheel. This is how the horizontal section shown in fig. 1 characteristics of the capacity of the Raduga 1 WPP.

If we draw a vertical line conditionally at a constant wind speed, for example, at V = 18 m/s, then the power graph at divides the power space into two zones: for modes whose power graphs pass above the power graph at , an increase in the angle leads to an increase in wind turbine power , and for modes whose power graphs pass below the power graph at

This feature of the modes of the windmill allows you to consider the possibility of adjusting the angle φ and setting each i-th blade separately and independently of other blades of the windmill as a function of the height of its position during each revolution of the

windmill. It is worth noting that, for example, under the same conditions, the power characteristic of each i-th blade will have the same character, but, for example, for three-blade wind turbines (as in the Raduga 1 wind turbine), the amplitude will be three times smaller.

Taking into account the above, for a small range of adjustment of the installation angle (for example, $0^0 \le \varphi \le 3^0$), we construct the power characteristic for one blade at different angles of one revolution of the windmill. At the same time, in order not to construct characteristics similar to fig. 7, let's use the capacity graphs $P_{BEV} = f(V, \varphi)$ in fig. 9. Since the range of wind speed changes over the entire height of the windmill is already known, each blade passes through all these values during one rotation of the windmill. At the same time, taking the power values from the graphs $P_{BEV} = f(V, \varphi)$, for example at $\varphi = 0^0$, we construct a graph for the i-th blade using the formula [8]:

$$P_{лоп(\varphi=0)i} = \frac{P_{BEV(\varphi=0)}}{3} = f(V), \tag{13}$$

The resulting graph is shown in fig. 10. This graph shows similar graphs for other values of the angle φ for one revolution of the windmill (where ω is the angular frequency of rotation of the windmill, t is time), as well as the graph of the bypass of these characteristics, in fact, provides for the operation of the wind turbine according to the bypass characteristics, according to fig. 9, which ensures the maximum efficiency of wind turbines. The envelope curve in fig. 10 shows at what angles φ of the installation it is necessary to adjust the blade in order to obtain maximum power and, accordingly, increase the production of electricity. Let's assume that when the blade is in the lower position (below the axis of rotation of the windmill), and when - in the upper position.

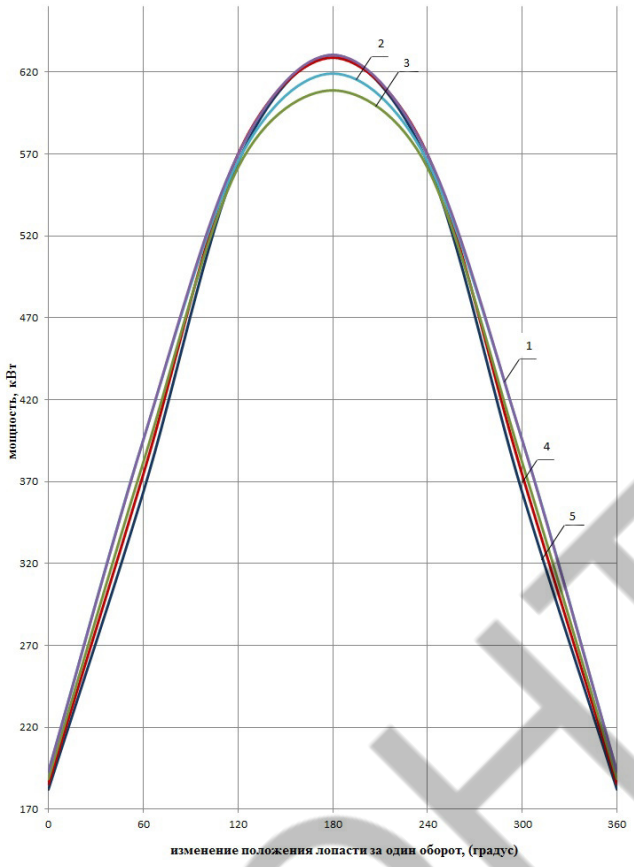

Fig. 10. Characteristics of the power produced by one blade for one revolution of the windmill (the height of the axis of its rotation of the windmill is 38 m) at different angles φ of the blades: 1 - bypassing all the characteristics; 2 - power characteristics of one blade at $\varphi=0^0$; 3- power characteristics with one blade at $\varphi=1^0$; 4- power characteristics with one blade at $\varphi=2^0$.

Next, we will consider options with three tower heights: 30, 38 and 50 m and determine the increase in production when using the system for adjusting the angle of installation of the blades. According to formula (6) – (7) and the characteristics in fig. 9. It is possible to calculate the power produced by the wind turbine at different angles φ of the blade installation.

The results of calculations for 30, 38 and 50 m are presented in Tables 1-3 (see appendix). According to these tables, it is possible to plot the characteristics of the power produced by one blade for one revolution of the windmill (the height of the axis of its rotation of the windmill is 30, 38 and 50 m) at different angles φ of the blade installation. In the graphic view for a height of 38 m, see fig. 10.

However, the windmill in our case has three blades shifted in space by 1200 relative to each other. Taking this into account, Fig. 11, three graphs (graphs 5, 6 and 7) of the power characteristics, similar to the one shown in fig. 10 bypass, also shifted in space by 1200 relative to each other. These three graphs are summarized. From fig. 11, it is obvious that the total graph (in Fig. 11, graph 2) of power clearly contains the third harmonic. The integral graph 3 of the total graph 2 and the integral graph 4 of the total graph calculated for the regime at φ = 0 ° are also given there. From the comparison of these two graphs, it

follows that with additional (to the main) adjustment of the installation angle in the range $0° \leq \varphi \leq 2°$, the increase in wind turbine power is ~ 1% [5].

At first glance, it seems that the percentage is too small for them to be seriously engaged. However, when creating the above-mentioned wind farm with a total capacity of 300 MW, where the installation of wind turbines of the company Vestas with a capacity of 3 MW is expected, the effect will conditionally be one additional unit. According to the generally accepted equation (7), the power was calculated under the same conditions, the graph of which is also shown in Fig. 11 (chart 1). From the comparison of graphs 1 and 3, it follows that for this wind turbine, equation (7) gives a result that is overestimated by ~ 15.3%.

For comparison, in fig. 12 and 13 show characteristics similar to fig. 11, but calculated for the heights of 50 m and 30 m of the axis of rotation of the same three-bladed windmill with a diameter of 48 m. At the same time, from the comparison of the integral graph 3 of the total graph 2 and the integral graph 4 of the total graph calculated for the regime at $\varphi = 0°$, it follows that with additional (to the main) adjustment of the installation angle in the range, the increase in wind turbine power for heights of 50 and 30 m of the axis of rotation is ~ 2.3 and ~ 1%, respectively.

In addition, from the comparison of graph 1, calculated according to equation (7), and the specified graph 3, it follows that for such a wind turbine, equation (7) gives a result that is overestimated by ~ 12.3% and ~ 6.4%.

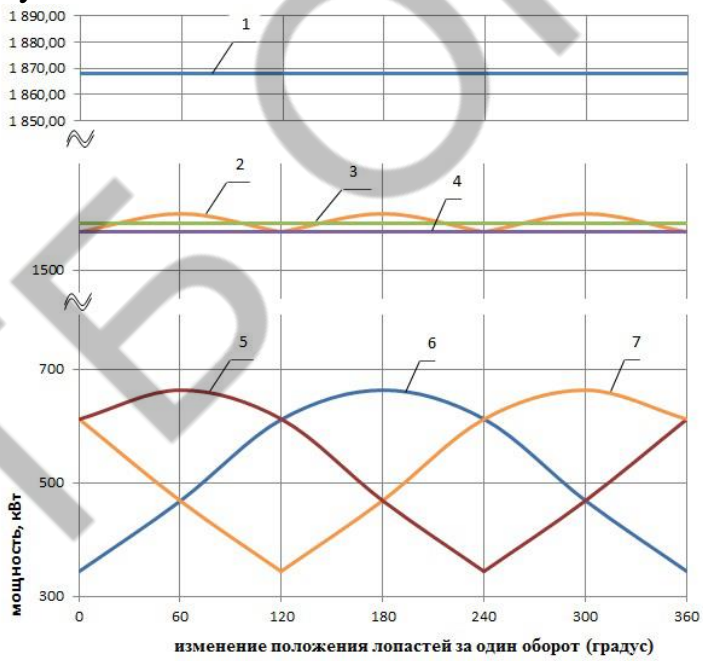

Fig. 11. Characteristics of the power of three blades with a displacement of 1200 relative to each other (the height of the axis of rotation of the wind wheel is 38 m): 1 - the power of the wind turbine, calculated according to the formula (3.7); 2 - total power calculated for bypass; 3 - integral power for schedule 2; 5, 6, 7 - characteristics of the power of three blades of a windmill with an offset of 1200; 4 - integral power, calculated for the blade installation angle $\varphi = 0°$

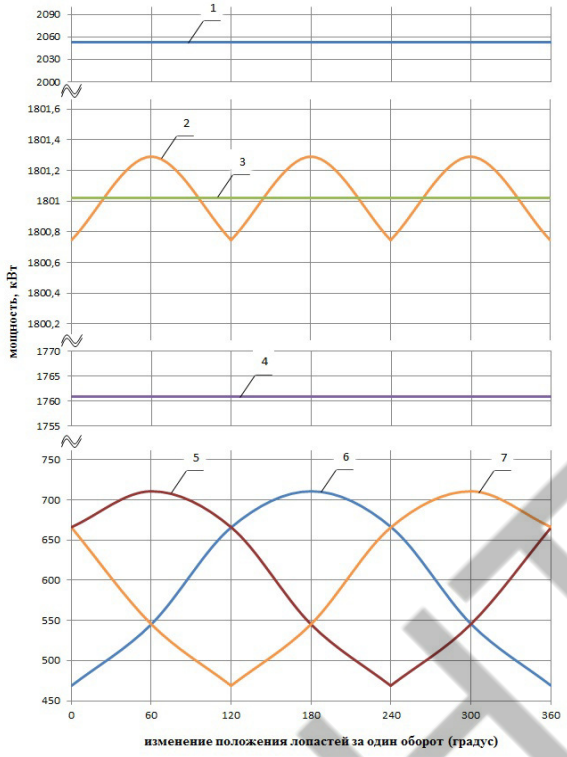

Fig. 12. Characteristics of the power of three blades with a displacement of 1200 relative to each other (the height of the axis of rotation of the wind wheel is 50 m): 1 - the power of the wind turbine, calculated according to the formula (3.7); 2 - total power calculated for bypass; 3 - integrated total power calculated for bypass; 5, 6, 7 - rotation of the blades along the contour, consisting of angles φ of rotation of the blade 0°, 1°, 2°, 3°; 4 - integral power calculated for the angle φ = 0 of blade rotation

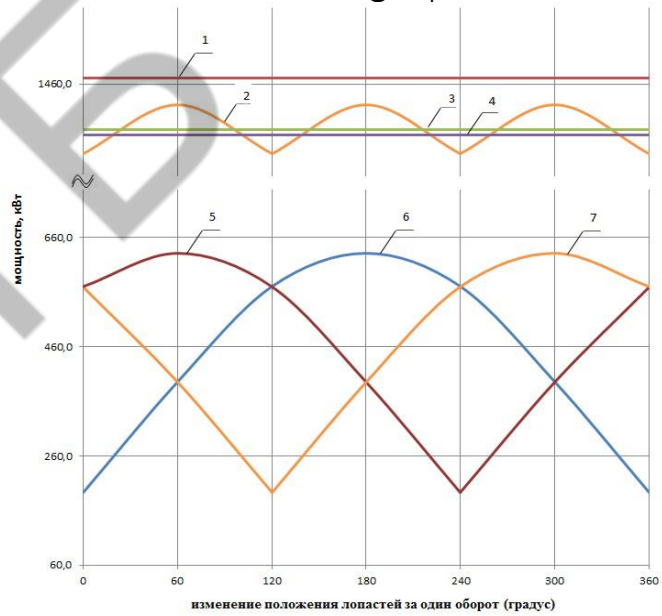

Fig. 13. Characteristics of the power of three blades with a displacement of 1200 relative to each other (the height of the axis of rotation of the wind wheel is 30 m): 1 - the power of the wind turbine, calculated according to formula (7); 2 - total power calculated for bypass; 3 - integrated total power calculated for bypass; 5, 6, 7 - rotation of the blades along the contour, consisting of angles φ of rotation of the blade 0°, 1°, 2°, 3°; 4 - integral power calculated for the angle φ = 0 of blade rotation

By additional adjustment of the installation angle of each blade individually within the range of 0°≤φ≤ 3° during each rotation of the windmill so that when the blade passes from the position below the axis of rotation to the top, the angle changes from a larger value to a smaller value, the efficiency of the wind turbine increases.

For the "Raduga 1" wind turbine with the height of the axis of rotation of 38 m and the radius of the wind wheel of 24 m, the power increase is ~ 1%. With an increase in the height of the axis of rotation of the same windmill to 50 m, the power increase is ~ 2.3%. When calculating according to the generally accepted formula (7), we get an overestimated result.

3. Possible practical implementation options

In the article [2] it is indicated that in the "Raduga-1" VEU, a modified gearbox of the MI-26 helicopter is used as a multiplier. As an option for practical implementation of the system for adjusting the angle of installation of the blades during each revolution of the VC, it is possible to consider the use of an automatic skewing of the blades * helicopter propeller, the diagram of which is shown in fig. 14.

The main difficulties when using this system [9]:

• the blade should make several swings in one revolution, oriented in the direction of the wind;

• systems and devices for rotating the blades represent significant complexity and reduce the reliability of wind turbines;

• wind installation becomes more dependent on wind direction.

All these problems are removed when using the blade skew machine in the adjustment system.

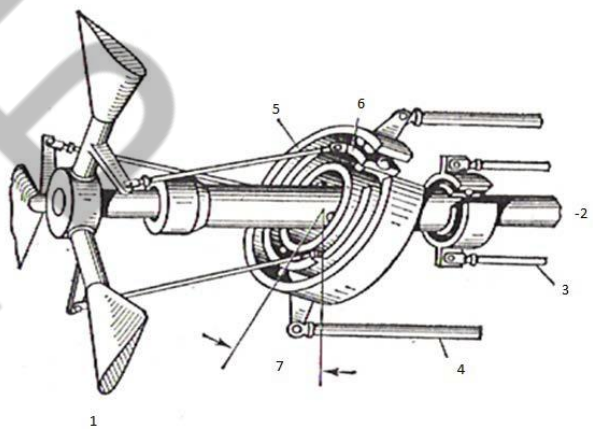

Fig. 14. Scheme of the automatic device for the angle of installation (automatic skewing) of the blades of the windmill: 1 - blade of the windmill; 2 - windmill shaft; 3. - control of the general pitch of the blades; 4 - control of the rings of the automatic blade installation angle; 5 - Does the ring of the blade installation angle machine not rotate; 7 - blade installation angle φ.

3.1. Statics

Blades 1 of the windmill with the possibility of turning around its longitudinal axis are connected to the common shaft 2, which is then connected, for example through a

multiplier, to the shaft of the electric generator. There is a cylinder on shaft 2 that can be moved along shaft 2. There are three rings located coaxially above the cylinder. The cylinder, inner ring and ring 6 form a cardan1 transmission, so they rotate with the same angular speed. The rotating ring 6 and non-rotating ring 5 form a bearing. The outer ring 5 of the bearing is connected to three rods shifted in space by 120 degrees. The bearing ring 6 is hinged to the levers of the blades 1 through the rods according to the number of blades 1 of the windmill. The cylinder is rigidly connected to the inner ring of the second bearing, the outer ring of which is hinged to the rod 3. Rods 3 and rods 4 are connected to by the unit for controlling the angle φ of the blades 1 of the windmill. Elements 4-6 form a skew machine [6].

3.2. Dynamics

During the rotation of the windmill, control of the angle φ of its blades 1 is carried out by two independent processes: cyclic control of the pitch of the blades 1 and control of the joint pitch of the blades 1. Cyclic control of the pitch of the blades is performed by the automatic skew.

Under the action of control rods 4, all three rings of the tilting machine are tilted thanks to the cardan transmission, causing a sinusoidal change in the angles φ of the blades 1 in a given range through the rods that control the blades 1. In turn, this causes the appearance of a sinusoidal component in the turning moment, which, therefore, develops the power of the windmill.

V. CONCLUSIONS

1. The method of choosing a wind turbine based on the assessment of the produced specific annual energy of the wind flow of a given area has been developed and proposed;
2. It is based on the fact that by additional adjustment of the installation angle of each blade in some cases within the limits of $0^0 \leq \varphi \leq 3^0$ during each rotation of the wind wheel so that when the blade passes from the position below the axis of rotation to the top, the angle changes from a larger value to a smaller value, the efficiency of the wind turbine increases. For the "Raduga 1" wind turbine with the height of the axis of rotation of 38 m and the radius of the wind wheel of 24 m, the power increase is ~ 1%. As the height of the axis of rotation of the windmill increases, so does the power.
3. When calculating the power of a windmill according to the generally accepted formula, we get an overestimated result compared to the method used in the work.

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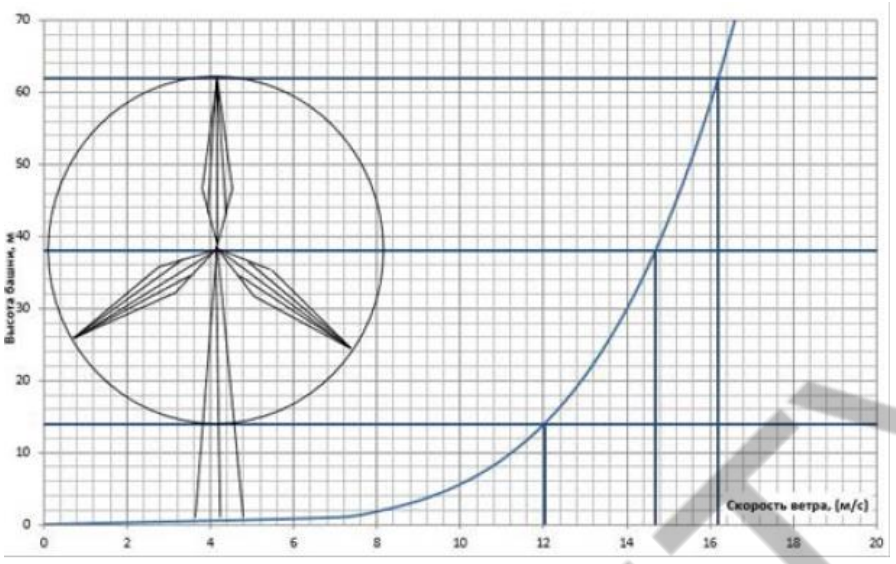
ADDITION



Graph of the change in wind speed along the entire height of the wind power plant (tower height = 38 meters)

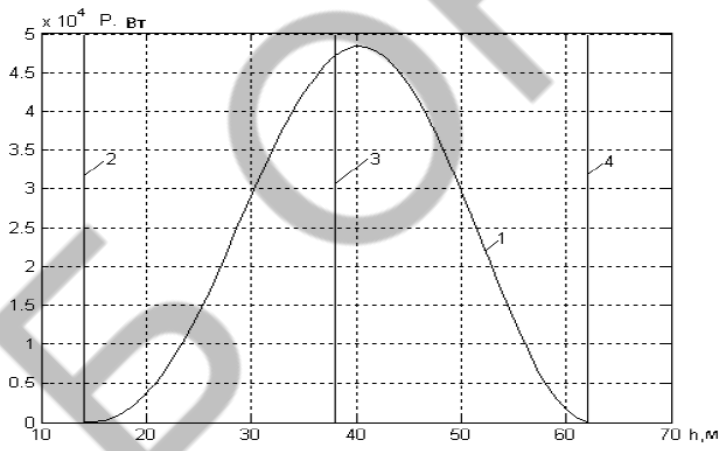


Fig. 7. Graph of distribution of the power developed by the windmill, taking into account its aerodynamic characteristics, by the area of the windmill and by its height - 1; vertical lines 2, 3, 4 - respectively, the height of the lower limit (14 m), the axis of rotation (38 m) and the upper limit of the windmill (62 m)

Table 1. - Characteristics of the power received by one blade for one rotation of the windmill (the height of the axis of its rotation of the windmill is 30 m) at different angles φ of the blades installation

The location of the blades		Speed, м/с	Z	Angle = 3^0		Angle = 2^0		Angle = 1^0		Angle = 0^0	
				C_m	P, Вт	C_m	P, Вт			C_m	P, Вт
blade below	0^0	10,1	8,9	0,0529	182,1	0,0538	185,3	0,0548	188,7	0,0560	192,7
	60^0	12,6	7,2	0,0680	363,4	0,0700	374,2	0,0715	381,8	0,0740	395,2
	120^0	15,0	6,0	0,0754	565,0	0,0760	569,8	0,0749	561,9	0,0754	565,4
blade on top	180^0	15,7	5,7	0,0761	630,6	0,0758	628,8	0,0735	609,0	0,0747	619,0
	240^0	15,0	6,0	0,0754	565,0	0,0760	569,8	0,0749	561,9	0,0754	565,4
	300^0	12,6	7,2	0,0680	363,4	0,0700	374,2	0,0715	381,8	0,0740	395,2
blade below	360^0	10,1	8,9	0,0529	182,1	0,0538	185,3	0,0548	188,7	0,0560	192,7

Table 2. - Characteristics of the power received by one blade for one revolution of the windmill (the height of the axis of its rotation of the windmill is 38 m) at different angles φ of the blades installation

The location of the blades		Speed, м/с	Z	Angle = 3^0		Angle = 2^0		Angle = 1^0	
				C_m	P, Вт	C_m	P, Вт		
blade below	0^0	12,0	7,5	0,066902	323,2	0,069458	335,6	0,071334	344,7
	60^0	13,6	6,6	0,073615	455,6	0,075191	465,4	0,075675	468,4
	120^0	15,5	5,8	0,076014	611,1	0,073901	594,1	0,075165	604,3
blade on top	180^0	16,2	56	0,075541	661,9	0,072672	636,7	0,073531	644,3
	240^0	15,5	5,8	0,076014	611,1	0,073901	594,1	0,075165	604,3
	300^0	13,6	6,6	0,073615	455,6	0,075191	465,4	0,075675	468,4
blade below	360^0	12,0	7,5	0,066902	323,2	0,069458	335,6	0,071334	344,7

Table 3. - Characteristics of the power received by one blade for one rotation of the windmill (the height of the axis of its rotation of the windmill is 50 m) at different angles φ of the blades installation

The location of the blades		Speed, м/с	Z	Angle = 3^0		Angle = 2^0		Angle = 1^0		Angle = 0^0	
				C_m	P, Вт	C_m	P, Вт	C_m	P, Вт	C_m	P, Вт
blade below	0^0	13,6	6,6	0,0720	445,8	0,0736	455,8	0,0752	465,6	0,0765	468,6
	60^0	14,3	6,3	0,0739	502,6	0,0752	511,6	0,0758	515,7	0,0758	515,3
	120^0	15,0	6,0	0,0754	566,0	0,0760	570,7	0,0749	562,6	0,0754	566,3
blade on top	180^0	15,2	5,9	0,0756	586,6	0,0762	591,3	0,0744	577,4	0,0753	584,2
	240^0	15,0	6,0	0,0754	566,0	0,0760	570,7	0,0749	562,6	0,0754	566,3
	300^0	14,3	6,3	0,0739	502,6	0,0752	511,6	0,0758	515,7	0,0758	515,3
blade below	360^0	13,6	6,6	0,0720	445,8	0,0736	455,8	0,0752	465,6	0,0757	468,6

IMPLEMENTATION OF AN ENERGY EFFICIENT DRIVING SYSTEM BASED ON THE CONSUMPTION OF ENERGY CARRIERS AS A WAY TO INCREASE ENERGY CONSERVATION IN HIGHER EDUCATION INSTITUTIONS

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Abstract. *The problem of energy conservation is a priority direction in the development of energy security of Ukraine. The importance of solving the energy conservation and energy efficiency problem in Ukraine increases by the fact that today there is no single possible recipe for eliminating losses of electrical energy on all elements of the power supply and power consumption system, that is to say, both in the processes of generation and transportation, and in the localization of its sources of electrical energy and its consumers structure.*

Increasing the efficiency of the energy industry and, first of all, energy, raw and financial resources minimization problems is one of the priority directions of our state. The solution to this problem is determined by the development of a complex of energy conservation measures, which is the realization of legal, organizational, research and production, power engineering and economic measures that contribute to the effective use of electricity and fuel energy resources.

By example of the National University of Life and Environmental Sciences of Ukraine considered the fundamental issues of planning and management of energy conservation measures by using the features of various methods in the direction of reducing electrical energy losses, increasing its energy efficiency and quality.

Keywords: *energy efficiency, energy conservation, energy carrier, saving, measure, housing and communal area, technology, modernization.*

I. INTRODUCTION

Obviously that in order to overcome the crisis in the energy industry, to provide the country's energy independence, it is necessary to form a new energy culture in all areas of life and to educate a new energy awareness generation.

To develop energy awareness among young people only by real examples of energy conservation and improving energy efficiency around. The university should become a basic innovation platform, which experience will help to educate a new generation of young professionals in the future, for whom a thrifty attitude to the consumption of energy resources will be the basis of professional and social activities.

The current experience of implementing energy conservation technologies in educational institutions of Ukraine witnesses that the problem of budget objects in general and educational institutions in particular is the irrational use of energy resources, the lack of necessary investments in the modernization of energy infrastructure.

II. LITERATURE ANALYSIS

Today, Ukraine is faced a number of significant problems with the energy supply of the communal industry.

In the recent past, the main factors of low energy efficiency of urban housing and communal heat supply, especially in small cities and towns were cheapness of energy resources and water, insufficient attention to stimulation of energy efficiency issues, as well as low qualification of service personnel.

Currently, Ukrainian industry and the domestic area are extremely energy intensive, they depend to a large extent on energy sources, first at all oil and gas, which are obtained from abroad. So, according to the International Energy Agency, in 2017, to generate $1 of GDP, Ukraine produced an amount of energy equal to 0.27 kg of oil equivalent. At the same time, Ukraine has a huge potential for energy conservation and energy efficiency [1].

Until recently, the problems of energy conservation, energy resources and water were basically was not solving at all, although funds were transferred from the budget to finance energy conservation [1, 2].

A high increase in tariffs for energy resources and energy carriers has changed a lot the attitude of the management of operating companies and its staff to the realization of their direct duties, although there are still many unresolved problems [1, 2].

The priority areas are the reduction of heat losses in heating systems by improving the thermophysical characteristics of building constructions, the introduction of heat shields for radiators, and finally, the development and implementation of automated accounting systems and regulation of coolant consumption at heating points. Payments for the consumption of thermal energy significantly decreased when heat and water meters were installed [3].

The level of reduction of heat consumption in heating systems depends on many factors, the main of which are heat losses through the enclosing surfaces, which determinate with the thermophysical characteristics of the surfaces, the type and characteristics of heat energy accounting devices, as well as the heat consumption regulation system.

The system of accounting and regulation of heat carrier costs for water supply in the residential area, which is implemented in an individual heating point, should ensure the regulation of heat carrier costs depending on the ambient air temperature and limit heat consumption at night time of the day and on weekends (holidays).

Installation of ways of accounting and regulation of heat energy consumption, creation of a centralized information and measurement system with further dispatching of it makes it possible to carry through full operational control by heat flows, which allows to reduce the volume of heat energy consumption by an average of 30% - 35% [3, 4].

The beginning of the introduction in world practice of a new direction of construction of structures with increased requirements to the level of energy exploitation efficiency appeared after the world energy crisis of 1974. It was a response to the criticism of experts of the International Energy Agency (IEA) of the UN that modern buildings have significant reserves for improving their thermal efficiency. At the same time, the scientific community showed their criticism in front of this decision due to the insufficient research of this issue,

the specifics of the formation of the thermal regime, and the inability of designers to optimize heat and mass flows in the areas and in the house [3, 4]. In the same report, IEA experts formulated the main idea of energy saving – energy resources can be used more efficiently by applying measures that are technically feasible, economically justified, and also acceptable from an ecological and social points of view, that is, they cause minimal changes in the usual way of human life.

As we know, Ukraine belongs to the countries with small energy reserves [3, 4]. At the same time, prices on the world market of energy resources are growing rapidly, and their reserves are running out. The process cannot be stopped, but it can be slowed down due to the introduction of energy efficient technologies in all areas, and first of all, in the housing and communal area, as one of the most energy intensive. Therefore, the main reason for the introduction of energy conservation technologies in the housing and communal area of the Ukrainian economy is the high cost of thermal energy [3, 4]. For example, the city of Kyiv today uses more than 2 billion m^3 of gas in the housing and communal economy during the year , and Ukraine at all uses more than 30 billion m^3 of gas per year [5]. The potential for gas savings in housing and communal economy is at least 30% (Fig. 1).

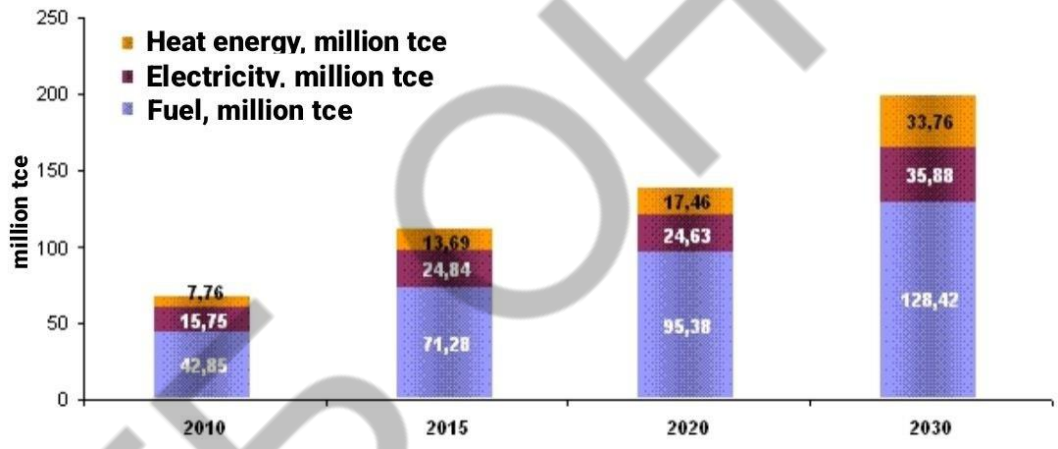

Fig 1. Energy conservation potential due to the technical (technological) factor [6]

So, about 90% of the existing communal and household fund, which is exploited at the moment, does not meet the heat efficiency requirements adopted in our state. Specific energy consumption of buildings in Ukraine in 2 - 2.5 times more than in developed countries located in similar climatic conditions. Due to this, increasing the energy efficiency of communal and household buildings is an urgent problem, and in order to solve the issues of optimizing the thermal regime of the building, improving its energy qualities, a thorough research of outside climatic and internal engineering and technical influences is necessary.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The development of the Comprehensive scientific and technical program of energy efficiency management at the National University of Life and Environmental Sciences of Ukraine for 2021-2025 (CSTP) aimed to introduce systemic energy management based on the results obtained and the experience gained in last years. The exploitation of experience gained during the period of realization of measures for the modernization of construction and engineering networks at the National University of

Life and Environmental Sciences of Ukraine during 2016-2020 allowed to focus attention on the introduction of modern fundamentals of energy management and optimal control of the university's energy carriers and water expenses in the conditions of constant increase in tariffs.

CSTP is a component in the realization of the strategic direction of the NUBiP of Ukraine within the area of the realization of the Development Program of the NUBiP of Ukraine "HOLOSIIVSKA INITIATIVE - 2025" regarding the reduction of expenditures on energy consumption through the implementation of organizational, technical and technological measures and material stimulation of energy conservation and energy efficiency improvement at the expense of the internal potential of the University.

Energy consumption by the buildings of the University depends to a considerable measure on the functional purpose of buildings and structures of primary and secondary educational and production purposes, which are used to provide the educational process.

CSTP is a conceptual document for the practical realization of the energy conservation policy, aimed at the implementation of the international standard ISO 50001:2018 "Energy management systems. Requirements and guidance for exploitation" at the university, which defines the requirements for the development, implementation, operation and improvement of the energy management system. ISO 50001 is based on the continuous improvement model of the management system, which is also used to develop other known standards such as ISO 9001 or ISO 14001. The mechanism simplifies the integration of energy efficiency measures during quality control, as well as monitoring energy and water consumption.

To ensure the implementation of ISO 50001:2018, it is necessary to ensure a number of requirements, in particular:

- the need to develop internal policies related to more efficient explotation of energy carriers during the educational process, scientific research, etc.;
- adjustment of goals and objectives according to the developed policy;
- implementation of continuous monitoring of energy and water consumption and application of this data for more effective decision-making according to energy efficiency management;
- analysis of monthly and seasonal results of energy consumption and forecasting of expenses for future periods;
- reviewing and adjusting the plan of energy efficiency management measures in according to current goals.

Based on the above provisions, the implementation of CSTP involves the step-by-step realization of measures with the development of project documentation and the corresponding technical and economic justification, namely:

- formation of an effective vertical of the university's energy consumption management, creation of an energy management service;
- attracting scientific, industrial and innovative resources to the realization of energy conservattion projects, creating demonstration zones of high energy efficiency and spreading experience in energy conservation issues;
- organization of internal consulting and information resources for the dissemination of experience on energy conservation issues among scientific and pedagogical workers, students and employees.

The realization of CSTP involves the analysis of the existing state, constant monitoring and forecasting of the development of energy consumption systems in the area of the current regulatory framework, the development of scientific and methodological support for the main, most effective areas of energy conservation activities, aimed at the realization of the energy conservation policy in university conditions.

The area of energy efficiency management and economical consumption of energy sources goes beyond purely technical issues of fuel and energy resources use and should be consistent with the principles and model of university development, positively influence on the structure of expenditures on energy supply, social and cultural aspects of energy explotation of scientific and pedagogical workers, employees and students.

IV. RESULTS

Obviously that in order to overcome the crisis in the energy area, to achieve energy independence of the country, it is necessary to bring up a modern energy conservation culture in all areas of being. Energy awareness among young people can be developed only by real examples of energy efficiency improvement.

The university, as a business subject, should be a basic innovative platform for the dissemination of experience and best energy conservation practices for the education and preparation of the modern generation of young professionals, for whom a thrifty attitude to the consumption of energy resources will be the basis of professional and social activities.

Productive use of energy resources is impossible without maintaining certain strategic principles for the development of the university's energy economy. A significant increase in energy tariffs in 2013, and after that as a result of military aggression in 2022, which made significant problems in the budgeting of expenses for the university's energy supply. The university immediately started the work with the development of project and estimate documentation and execute thermal modernization of buildings of educational buildings and student dormitories by attracting grant investments. Currently, the thermal modernization of 10 educational buildings and partially 5 student dormitories has already been completed.

For several years in a row, the National University of Life and Environmental Sciences of Ukraine has been developing and implementing organizational and technical and technological measures to reduce levels of energy consumption and is creating a new environment for making effective management decisions to stimulate energy conservation at the expense of the university's internal potential.

First at all, program documents were developed for the implementation of the energy consumption management system based on real-time data analysis, energy audits and energy inspections of university buildings were performed according to current regulatory documents (Fig. 1). In the future the available data were used to determine the forecast indicators of technical and economic justifications for future projects.

During the period of 2014-2020, a comprehensive system of energy management formed in the university, based on the Education and research institute of Energetics, Automatics and Energy saving, the Center for Energy Efficiency was created, which became a kind of specialist unit for the engineering services and heads of structural

divisions for monitoring energy and water consumption, regulating the regimes of heating stations, technical and economic justifications of the proposed measures, etc.

The mission of the first stage was to determine the generally corresponded to existing and perspective potential for energy conservation, to develop and justify priority and perspective measures to increase energy efficiency.

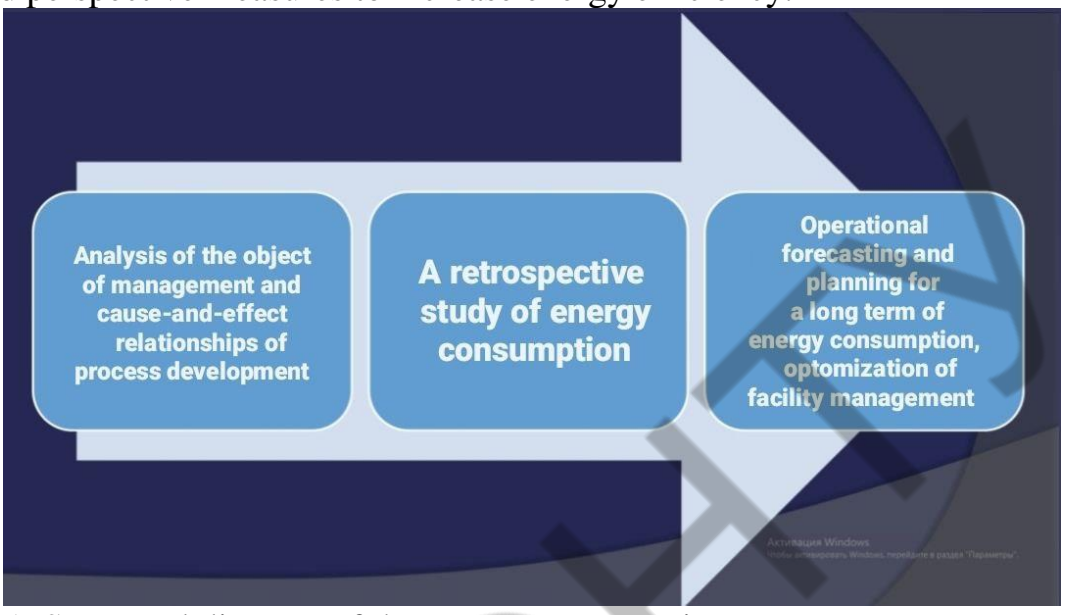

Fig. 1. Structural diagram of the energy consumption management system

The first steps related to the installation of modern accounting units for energy carriers and water in all buildings, modern heating points with weather dependent regulation of the supply of the heating medium were installed, which made it possible to identify cases of irrational exploitation of energy carriers and adaptively manage energy and water consumption (depends to the season, the academic period, on weekends and holidays, time of day, etc.) (Fig. 2).

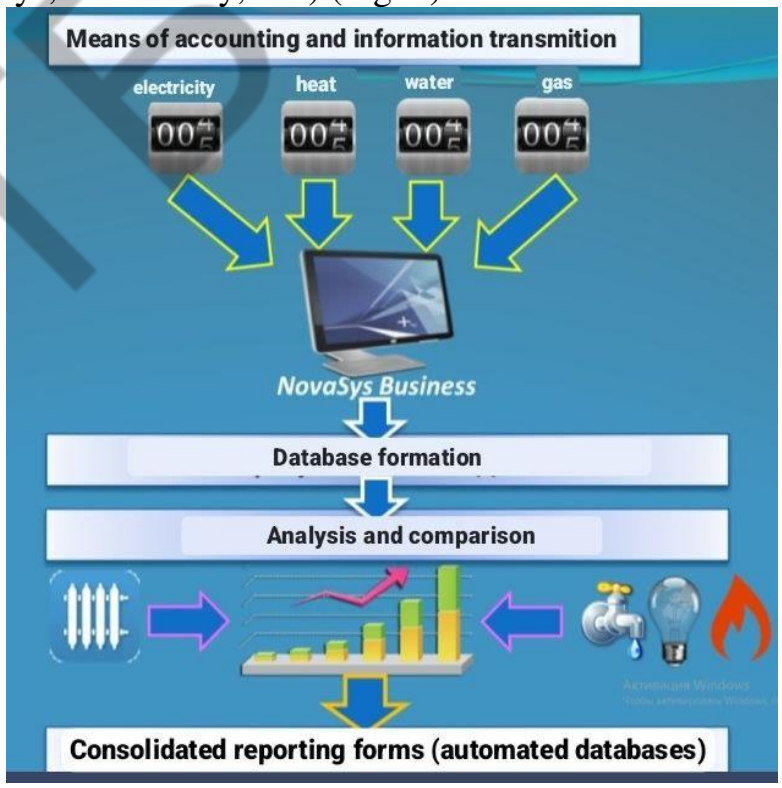

Fig. 2. Structural scheme of energy consumption

According to the order of the rector, in 2015, the university began a phased reconstruction of the heating stations of the educational buildings with the use of internal circulation pumps, control valves, hydraulic pressure regulators and heat exchangers, which ensure effective regulation and balancing of thermal power. Object oriented algorithms the regulation were developed by our specialists.

At the same time, constructive cooperation was adjusted with the companies supplying electricity and thermal energy to settle the issues of tariffs in the dormitories use, which led to a significant decrease in the financial costs of the university. In 2017, technical changes were made to the system of commercial accounting and the terms of application of contractual tariffs, which made it possible to reduce the financial burden on the university budget by more than UAH 700,000 per year. Today, boiler units for hot water accounting have already been installed, which make it possible to account only for actually consumed thermal energy. The development of the project of the automated commercial electricity accounting system with the modernization of accounting schemes is at the stage of completion, and the pilot project of software installation for ASKOE NUBiP of Ukraine has been completed.

Incandescent lamps were replaced with energy conservation ones with a reduction of the installed power of lighting devices by 79%, reconstruction of external electrical networks was carried out, pilot projects of an automated lighting control system were implemented in common areas, electric boilers were installed in student dormitories and dining halls; energy inspections of educational buildings were performed.

A method of normalizing energy consumption limits has been implemented, and their use is constantly monitored. In addition, since 2018, PJSC DTEK "Kyiv Electric Networks" compensates the university for expenses for the joint exploitation of external power networks in the amount of about UAH 200,000 per year.

Retrospective data on consumption (Tab. 1) and expenditure on energy and water (Fig. 3) at the university during 2016-2020 are indicative of the evaluation of the Center's performance. They testify that the internal engineering systems of energy consumption, educational buildings, dormitories, etc. still contain significant practical energy saving potential.

Table 1. Costs of energy and water consumption at the university in 2014-2020, thousand UAH

Type of service	**Funds were actually paid at current rates, thousand UAH**						
	2014	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Heat consumption (heating)	9900	10118	16105	11676	16609	14103	11407
Hot water	2843	3388	6960	6583	4712	6160	4536
Water consumption	1296	2349	3271	3417	3552	4915	4330
Electricity consumption	6100	7496	11585	10299	10757	10954	7881
Gas consumption	1007	1449	2334	1531	1980	1483	863
IN ALL:	**21146**	**24800**	**40256**	**33507**	**37612**	**37616**	**29019**

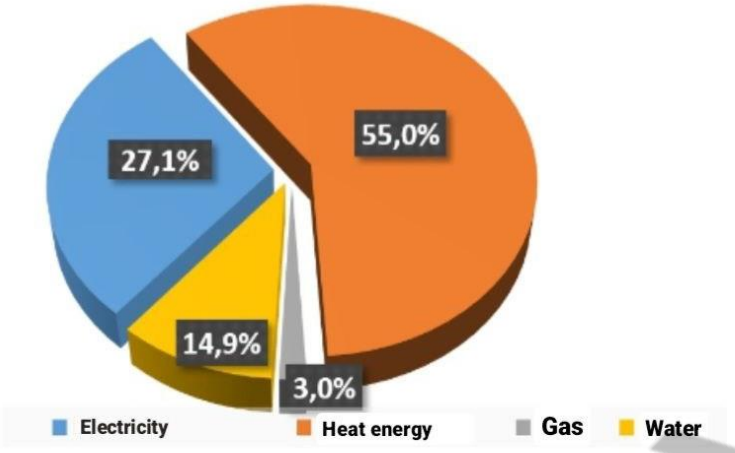

Fig.3. The pie chart of expenses for heat and water supply of the university as of 2020

To assess the scope of the work, we should to conduct a basic analysis of indicators regarding the levels of energy consumption in physical and monetary units. Such retrospective data by year eloquently tells about the successful work of the entire team (Fig. 4-9).

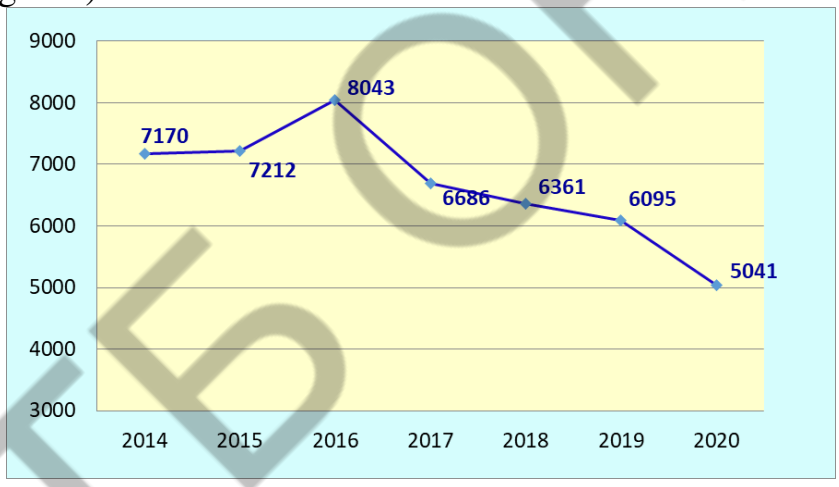

Fig.4. Dynamics of electricity consumption in 2014-2020, thousand kW·h

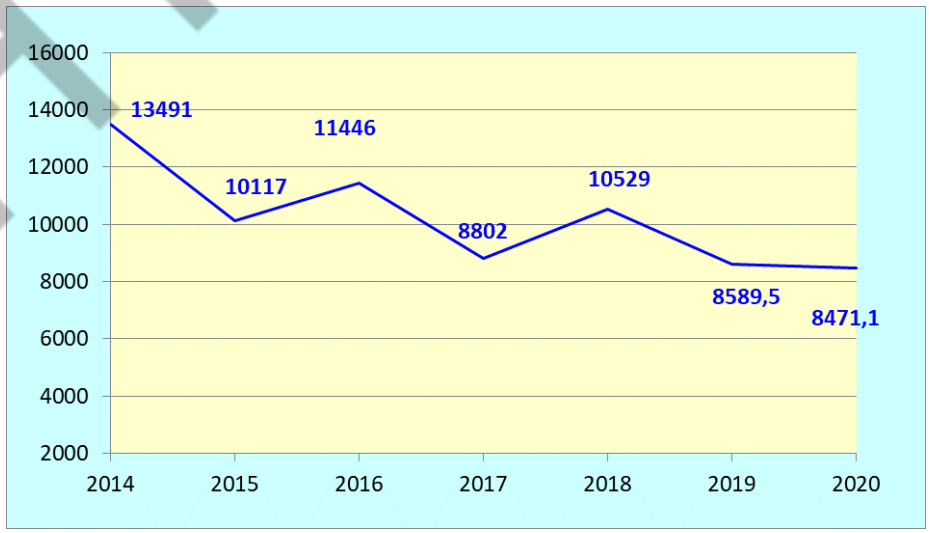

Fig.5. Dynamics of heat consumption in heating systems in 2014-2020, GKal

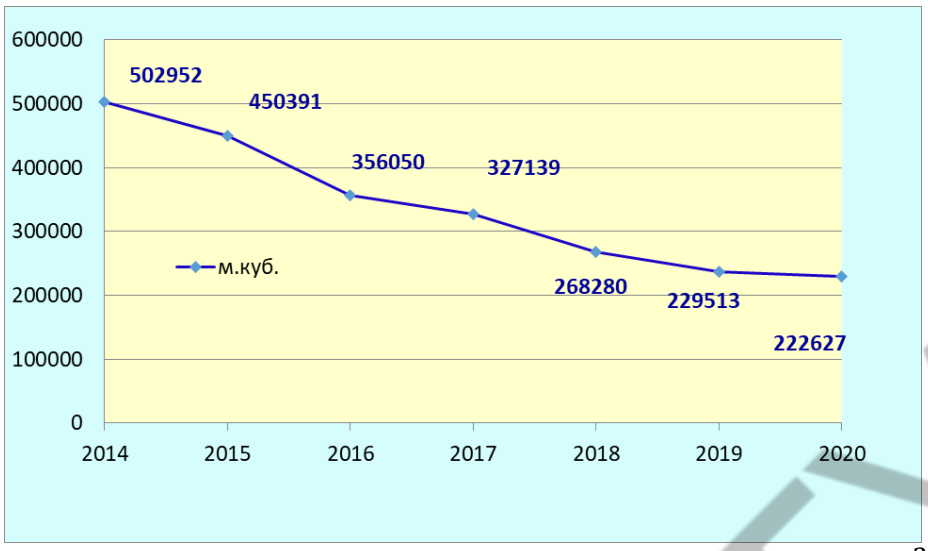

Fig.6. Dynamics of cold water consumption in 2014-2020, m^3

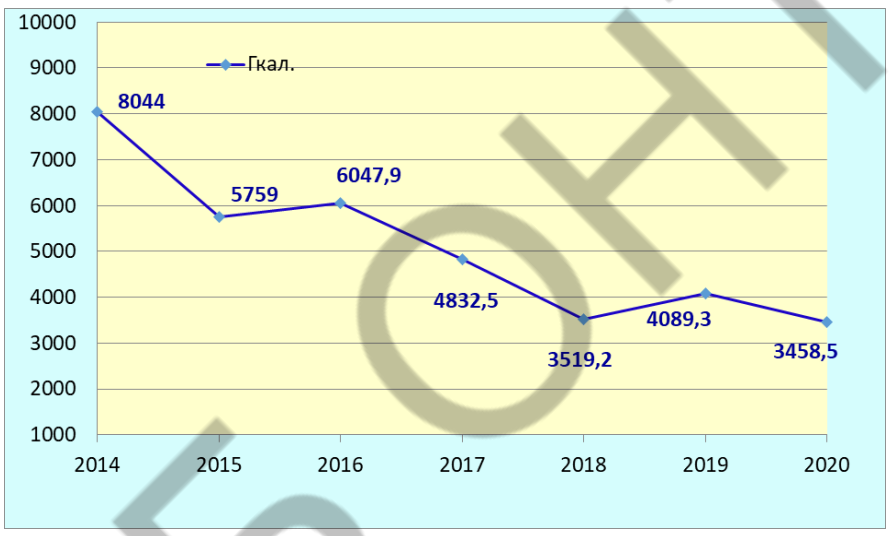

Fig.7. Dynamics of heat consumption for hot water preparation in 2014-2020, GKal

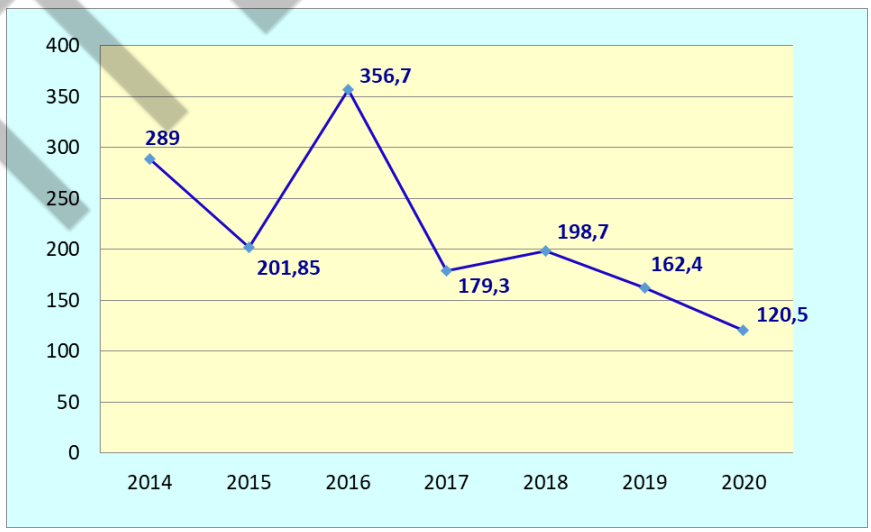

Fig.8. Dynamics of natural gas consumption in 2014-2020 in thousand m^3

Fig.9. Total expenses for energy carriers in 2013-2020

From a practical point of view, it became important to use the technical and intellectual potential of scientific and pedagogical workers of the energy efficiency center of NUBiP of Ukraine, and specialists of engineering services of the university. It was their effective work that made it possible to implement effective energy consevation activities, conduct comprehensive energy surveys of buildings and structures, propose ways of attracting material and financial resources for energy conservation measures, and modernize buildings and engineering networks.

Today, an energy management service based on the rationing of energy and water consumption in buildings is functioning in the university, specialized software and technical support for managing energy and water consumption is being implemented, and a motivation system for employees has been created.

It is worth mentioning the great work of engineering services, scientific and pedagogical workers, heads of structural units, who made a significant contribution to the realization of the university's energy conservation policy. So, for example, Fig. 10 shows the economic effect of the implementation of energy conservation measures until the year of 2014.

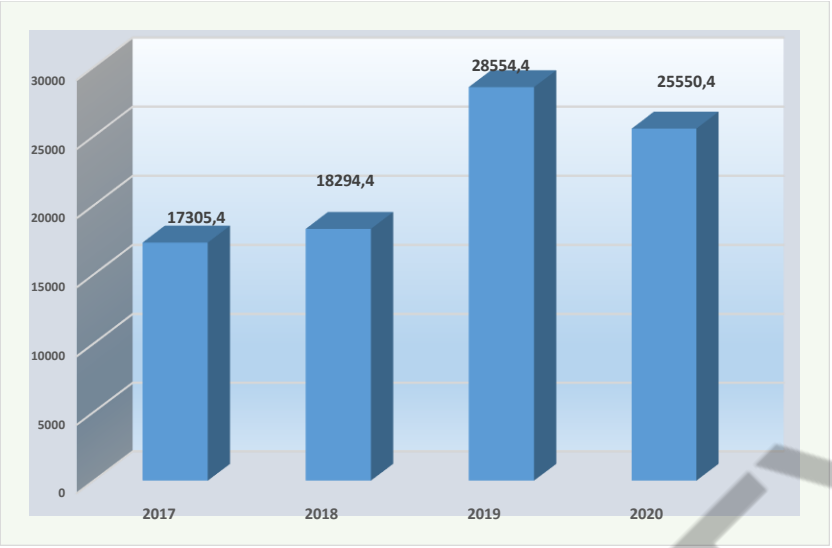

Fig.10. Economic effect to the basic in 2014

During the operation of the energy conservation program in NUBiP of Ukraine in 2017-2020, the total economic effect in the given tariffs of the year of 2014 for energy carriers and water was 89.76 million hryvnas, so the university would pay 89.76 million hryvnias more for energy carriers over the course of 4 years.

The further realization of the program involves the implementation of automated software and technical complexes for managing energy consumption modes and evaluating the economic efficiency of implementing energy conservation measures in university conditions. Modern possibilities of energy efficient improvement of buildings and systems, intelligent regulation of energy consumption require further development.

The experience gained at the university is unique. At the same time, it is available for distribution. NUBiP of Ukraine achieved a significant economic effect due to energy efficiency without attracting state funds by using internal reserves thanks to innovations that they developed themselves.

Energy efficiency should become a kind of criterion for the quality of functioning of the general university economy, coordinated interaction between engineering services, heads of structural and separate divisions, employees and students (Table 2, Table 3, Fig. 11).

Table 1.2 Analysis of tariff growth (by year)

Type of service (energy carriers)	Units of measurement	2019 p	2020 p	2021 p	The nearest perspective from 01/04/21
Electricity	kW/h (educational building)	2,29	2,29	2,49	3,49 (+30%)
	kW/h (dormitories)	0,9	0,9	1,68	1,68
Heating	Gcal	1259	1360	1679	1679 (+23%)
Hot water	Gcal	1246	1356	1522	1654 (+22%)
Cold water	Square meters	20,82	22,99	25,48	25.8 (+11%)
Gas	Square meters (educational building)	9,42	7,17	9,87	9.18 (+28%)
	Square meters (dormitories)	5,69	7,17	7,33	9.18 (+28%)

Table 3. Analysis of energy consumption in 2020

Energy carriers	Unit of measurement	2019		Outlay, thousand UAH
		consumption	value, thousand UAH	
Electricity	kW·h (educational building)	2742000	7936,3	**9570**
	kW·h, (dormitories)	3353084	3017,7	**5969**
Heating	Gcal	8589,5	14103,2	**14422**
Hot water	Gcal	4089,3	6160,2	**6764**
Cold water	m^3	251252	4915,5	**6482**
Gas	m^3, (educational building)	97450	918	**895**
	m^3, (dormitories)	59950	564	**550**
In all			**37614,9**	**44652**

Fig. 11. General expenses for payment of energy carriers

V. CONCLUSIONS

The development of the Comprehensive scientific and technical program of energy efficiency management at the National University of Life and Environmental Sciences of Ukraine for 2021-2025, the introduction of system energy management based on the results obtained and the experience gained in recent years, made it possible to focus attention on the introduction of modern principles of energy management and optimization of the university's expenditure management for energy carriers and water in conditions of constant increase in tariffs.

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MODELS OF REFRIGERATING DEVICES IN THE OPEN MODELING SYSTEM TT-RH

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Abstract. *In the TT- RH system, the subject basis is modules that describe elementary processes in various elements of installations, both main and auxiliary, in uniform requirements that ensure the correctness and simplicity of their joint interaction; conditions of joint operation of these modules; universal algorithms for creating arbitrary control programs that depend on external modeling conditions. The structure of the subject area of the TT- RH open system consists of modules of several levels. Thanks to this, it is possible to simulate the scheme of any refrigerating machine in the working range of boiling and condensation temperatures, and the refrigerating (thermal) capacity of the installation itself. You can choose the cooling medium and the cooling coolant and so on. It is possible to make an effective selection of the compression mechanism, and if there is a large range between temperatures, switch to a multi-stage installation. At the same time, it is possible to choose the most effective regular mode of operation, observing the specified limits of power and operating temperatures. All this and much more, for example, the choice of an effective regenerative heat exchanger of its brand and heat exchange surface, as for refrigerating machines, can be successfully and efficiently carried out with the help of the open modeling system TT-RH.*

1. MODELS OF REFRIGERATORS BASED ON THE OPEN MODULAR SYSTEM TT- RH

1.1. Simulation of the operation of refrigeration devices

Today, the means of computer technology for the analysis and synthesis of complex technical objects lead to the need for the development of universal means of forming models of refrigerating units that flexibly implement any possible regulation schemes and programs. The requirements for generating such models are [1...4]:

- both structural and parametric analysis of R M's work;
- display of the physical essence of the formation of the model during the implementation of the production scheme;
- basing the subject area on single universal output modules;
- commonality and availability of means of forming models;
- the stability of the computing process with the possibility of effective accuracy control;
- simplicity and availability of interactive tools.

Taking into account the specified requirements, an open universal multi-level modular system TT- RH was developed for the formation of the installation model,

which works according to the combined scheme RH (R - refrigeration - cold; H - heating - heat), which provides a parametric and structural analysis of the operation of various R M schemes on stages preceding the immediate design and construction process (Fig. 1)

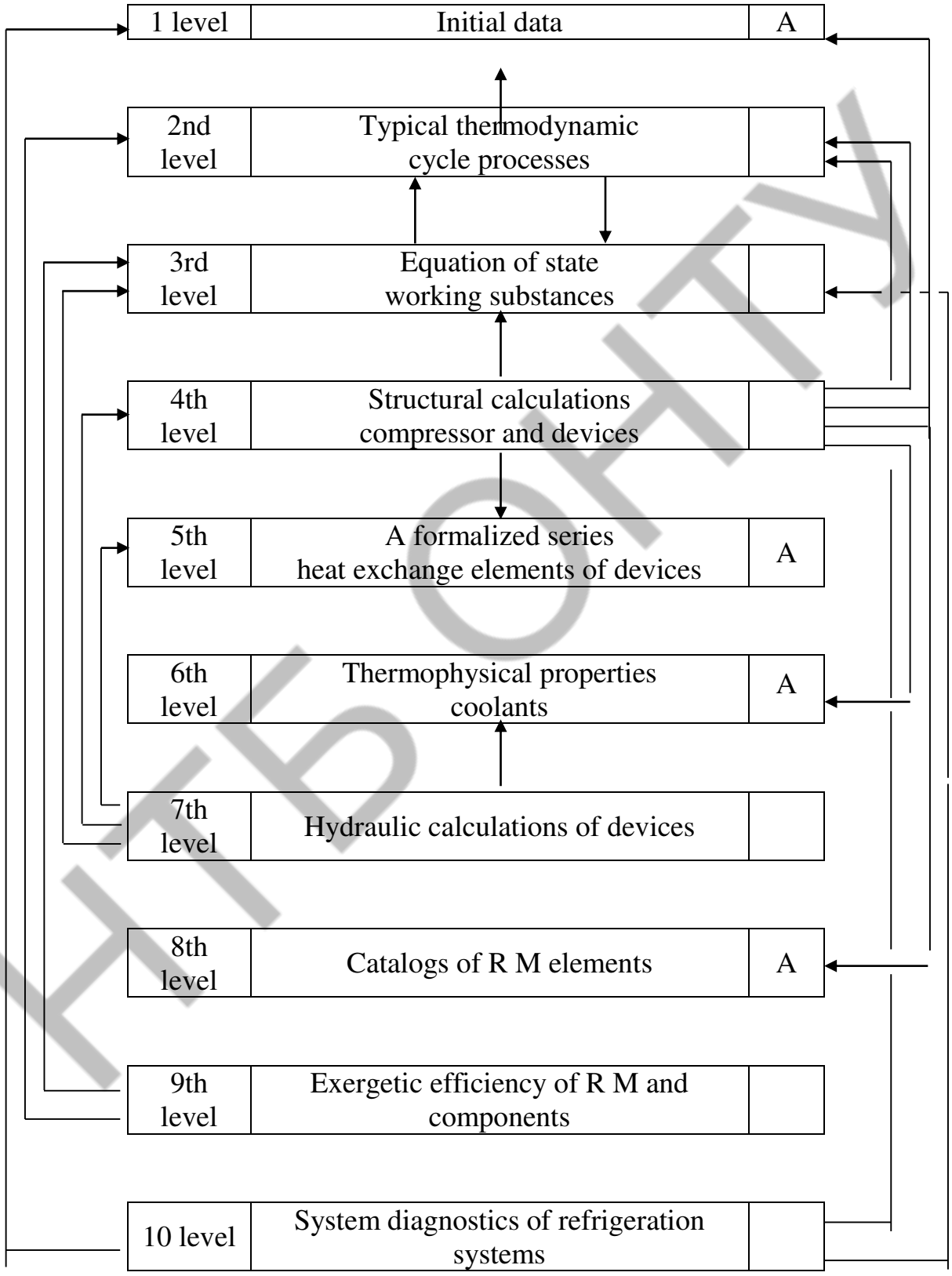

Fig. 1. The structure of the open multi-level modular system TT–RH

The formation of RM modules in the TT-RH system is based on the principle of built-in cycles, which allows for the physical interpretation and universality of the module formation process. In the TT-RH system, the subject basis is modules that describe elementary processes in various elements of installations, both main and auxiliary, in uniform requirements that ensure the correctness and simplicity of their joint interaction; conditions of joint operation of these modules; Universal algorithms for the assignment of arbitrary control programs that depend on external modeling conditions [2...4, 7].

1. 2. The structure of the subject area of the TT-RH open system

The structure of the subject area of the TT-RH open system consists of modules of several levels.

The first level consists of output data modules describing elementary procedures: selection of cooling capacity, condensation temperature depending on the physical properties and aggregate state of the cooling source and its initial temperature; selection of the boiling temperature depending on the physical properties and aggregate state of the cooled medium and its initial temperature, etc. Modules of the first level are autonomous and do not contain references to modules of other levels.

The second level of the module describes typical thermodynamic processes occurring in the selected cycle: compression in the compressor, expansion in the throttle valve, heat exchange in the main and auxiliary heat exchange devices, as well as the main operational characteristics (pressure difference in the cycle, their ratio, etc.). The functioning of the modules of the second level is carried out through calls to the modules of the first and third levels.

The third level of the module is the equations of state of the corresponding types and modifications of the selected working body, which allow unambiguous determination of thermodynamic parameters at the nodal points of the cycle. This level also contains modules that allow you to determine the thermophysical properties of the working body in different aggregate states based on the corresponding equations. The functioning of the modules of the third level is carried out in interaction with the modules of the second level.

With the help of modules of the fourth level, standard design calculations are carried out according to the main indicators and characteristics of devices, main and auxiliary heat exchange devices. The operation of all modules of this level involves addressing them to modules of the first, second and third levels, and some modules of this level additionally interact with modules of the fifth and sixth levels.

The fifth level of the module is a formalized series of elements that are used as elementary heat exchange elements. All their characteristics are standardized. The modules of this level are autonomous and do not depend on the modules of other levels.

Sixth -level modules contain data that determine the thermophysical properties of heat carriers, such as water, soda ash solution, air, etc., which are used in the main heat exchange devices of the HM. They do not depend on other level modules and function autonomously.

Modules of the seventh level. With their help , appropriate hydraulic calculations

of the main and auxiliary heat exchangers are carried out. Their functioning is based on interaction with modules of the third, fourth, fifth and sixth levels.

Modules in the eighth level are - catalogs with the main components of RM, formed on the basis of existing standards for them according to the main characteristics and parameters. They can be accessed by modules of the fourth and tenth levels.

Modules of the ninth level consist of modules that implement exergy analysis of thermotransformers in general and for links separately with the determination of their efficiency based on relative losses. These modules interact with modules of the second and third levels.

The corresponding modules of the open diagnostic subsystem are connected to the last , tenth level , which, interacting with the modules of the first, second, and third levels, determine irreversibility in the operating installation, additional costs of energy raw materials for their elimination , and identify effective modes for given values.

Universal principles of synthesis of RM models from modules of these levels are based on the following conditions:

- continuity of the flow, which ensures the preservation of the flow balance;
- power balance, heat balance, conditions imposed by regulatory programs;
- aggregate state of the working body.

This approach allows you to imagine the complex process of model synthesis from typical elementary modules in a simple and accessible way for users who do not have the qualifications of a professional programmer. The RM model of an arbitrary scheme is formed from the output modules of the sequence, which reflects the structure of the selected installation scheme.

The open TT- RH system uses the following standard numerical methods for solving systems of equations; the method of nested cycles, which is divided into the method of bisections and the method of chords [1 , 4, 8]. To develop the TT-RH system , the rapid application development environment was used [6 , 10, 11 , 14].

An example of a work session with the TT–RH system is shown in Fig. 2.

Unfortunately, a fragment with calculations for the working fluid R717–ammonia, which in itself is a very toxic substance, got here. But all this has a relatively negative resonance.

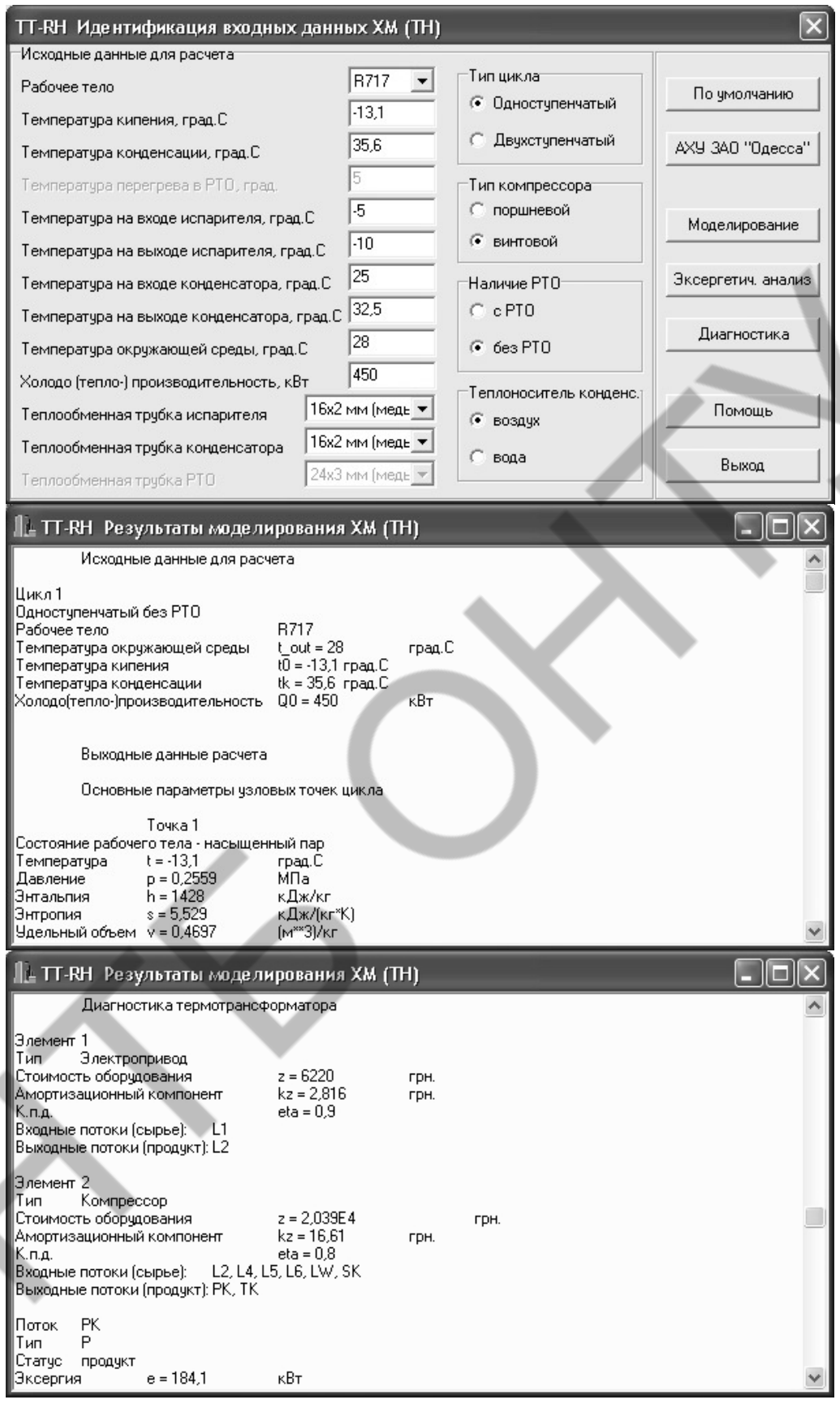

Fig. 2. Working with an open TT–RH system

1.3. Formalization of the scheme of a single-stage vapor compression refrigerating unit

The formalized diagram of a single-stage vapor compression unit in the TT-RH system is shown in Fig. 3. In the analyzed model, two modules: "Input of the working body" and "Output of the working body" are designed to assign flow parameters, respectively at the entrance, i.e. in the place of a virtual break in the closed circuit (the place of connection of the capacitor and the choke is selected) and obtaining the parameters at the output. Thus, by varying the values of the input parameters of the "Input working body" module, it is possible to study the behavior of the installation under different operating conditions for different working bodies. The thermodynamic calculation of the installation according to this model is carried out in accordance with the algorithm that implements the sequential calculation of the component modules with the given values of the cycle parameters.

2. FORMATION OF MODULES OF OPEN SYSTEM TT–RH

2.1. Formation of modules of the first level

modeling of steam compression TT according to the RH scheme of the first level models are selected as autonomous and ultimately determine the choice of thermodynamic cycle, structure and composition of TT elements.

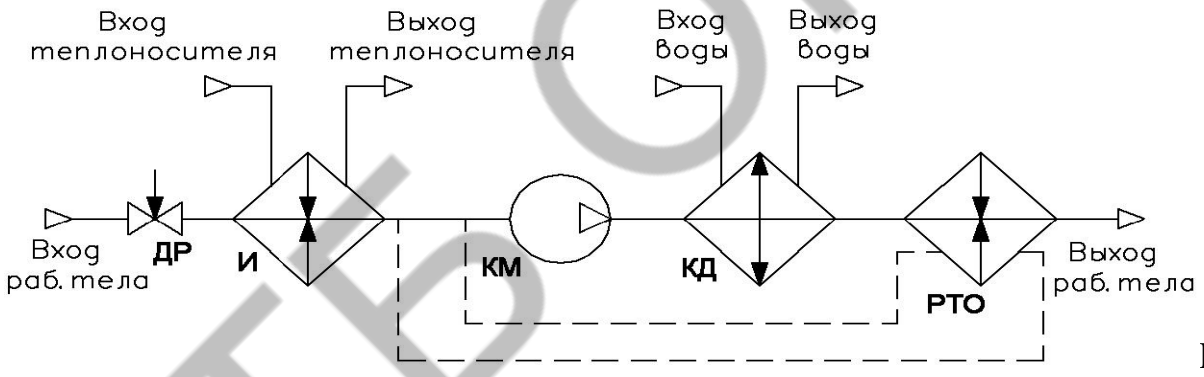

Fig. 3. A formalized scheme of a single-stage vapor compression plant in an open TT-RH system

IN modules of this level are given output data:

cooling capacity Q_o, kW;

boiling point in the cycle $t_o, {}^oC$;

condensation temperature in the cycle $t_к, {}^oC$;

temperature of the cooling coolant, initial $t_{w_1}, {}^oC$;

temperature of the cooling coolant, final $t_{w_2}, {}^oC$;

the initial temperature of the cooling medium $t_{s_1}, {}^oC$;

the temperature of the cooling medium is final $t_{s_2}, {}^oC$.

In the dialogic open system of TT-RH, the modules of the second, fourth and

tenth levels address the modules of the first level.

2.2. Formation of modules of the second level

2.2.1. Module "Typical thermodynamic processes in a single-stage vapor compression unit"

The basis of this module is thermodynamic processes during the calculation of the specific thermal characteristics of the cycle.

For this purpose, the output data in the modules of the first level are pre-set: t_O, t_K, $Q_o(Q_к)$; in modules of the third level - by the working body and the amount of overheating in the regenerative heat exchanger Δt_{n2}, *city*

The scheme and cycle of a single-stage steam compression installation are presented in Fig. 4 and 5. The scheme allows the operation of the installation with and without the RTO.

The compressor (KM) compresses the vapors of the working medium to pressure $p_{к}$ (process 1–2) and pumps them into the condenser (KD), in which, due to heat exchange with the cooling medium, the aggregate state of the working medium changes

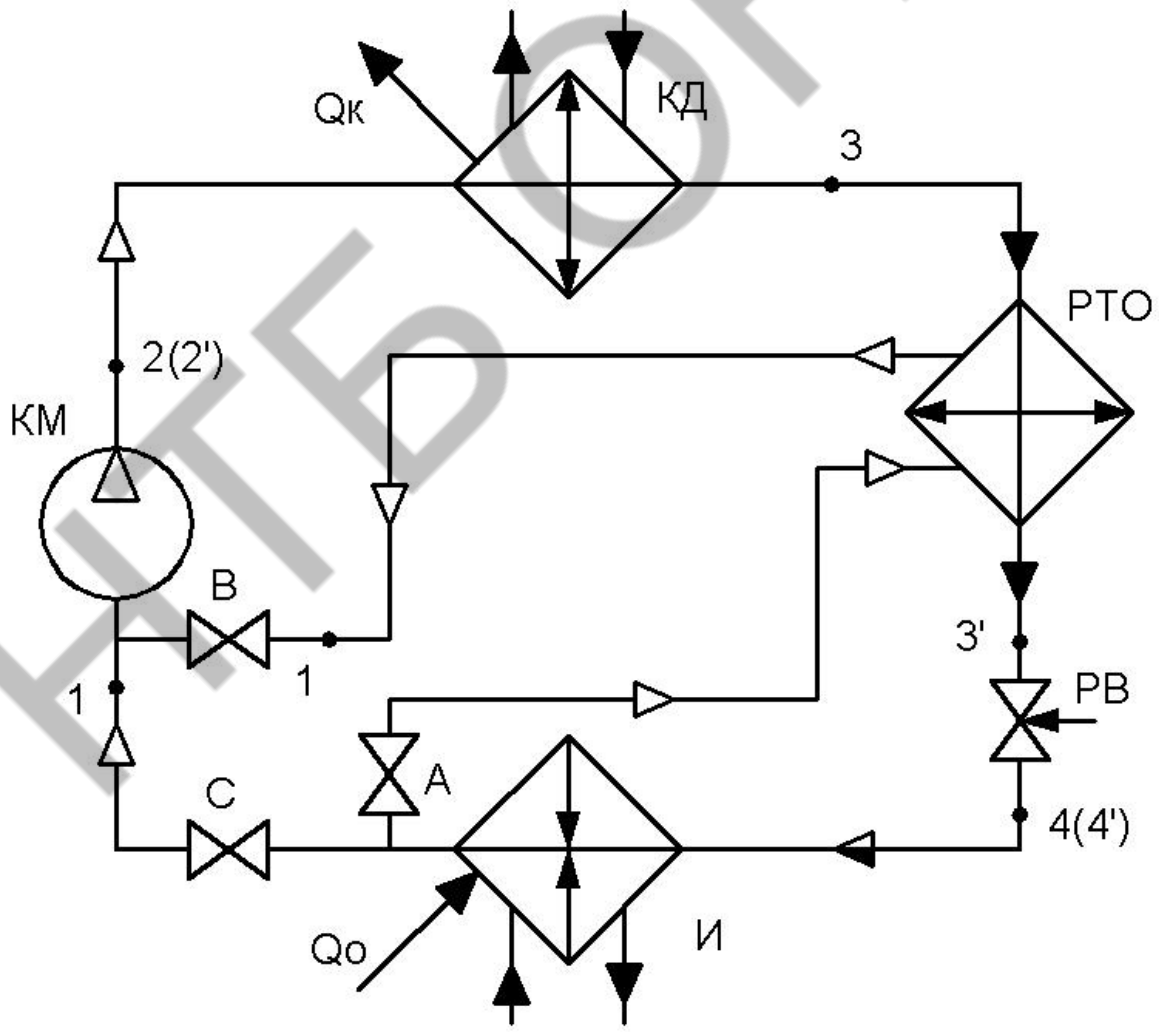

Fig. 2.4. Scheme of a single-stage steam compression installation

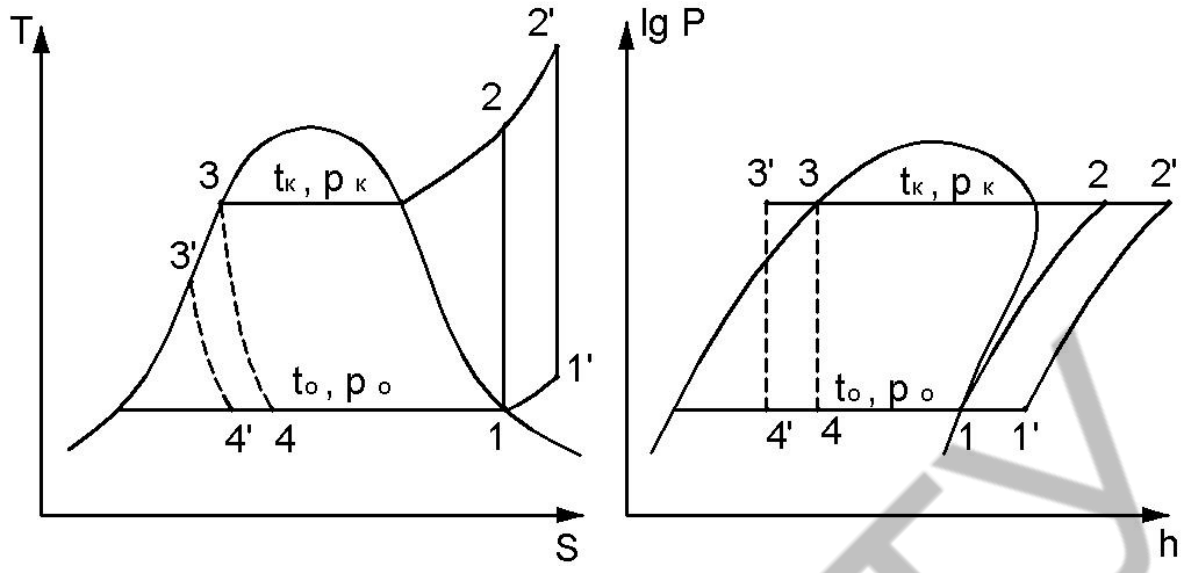

Fig. 5. The cycle of a single-stage vapor compression plant.

bodies - condensation (process 2-3). Then, the condensate is throttled in the control valve (RV) to the pressure p_o (process 3-4) and in the form of a vapor -liquid mixture enters the evaporator (B), where it boils due to heat removal from the object being cooled (process 4-1). The vapors formed are sucked off by the compressor (KM) and the cycle is closed.

According to the above schemes and installation cycles, the parameters at the nodal points of the cycles are determined depending on the selected working body. Calculation of the main thermal characteristics RM was carried out according to known methods.

2.3. Formation of modules of the third level

To carry out engineering calculations and scientific research, it is necessary to have information about the thermodynamic and thermophysical properties of the working body. Designing in an interactive mode of operation causes certain difficulties when using standard tables and diagrams of the properties of substances common in engineering assessments of the thermodynamic efficiency of RM cycles. The most effective is the use of aggregated models of equations of state, knowing the parameters of which, you can reproduce all the necessary thermodynamic information in a minimum time.

2.3.1. Module "Thermodynamic properties of R134a"

According to the Montreal Protocol, signed in 1987, it is envisaged to reduce the production and use of ozone-depleting refrigerants and mixtures based on them [27]. In this regard, the alternative refrigerant R134a (1, 1, 1, 2 – tetrafluoroethane / CH_2FCF_3), belonging to the ethane group of derivatives, was used as a simulating working medium in TT cycles. The use of R134a instead of R12 allows, in the case of high boiling temperatures, to increase the energy efficiency of thermotransformers and, under certain conditions, even at relatively low boiling temperatures [17].

The main parameters of 134a [1,4,..,17}: normal boiling point, $T_{н.к} = 247{,}02\,°K$; molecular weight, $M = 102{,}032\ кг/кмоль$; critical temperature, $T_{кр} = 374{,}18\,°K$; critical pressure $p_{кр} = 4{,}059\ МПа$; critical density, $\rho_{кр} = 508\ кг/м^3$. To calculate the thermodynamic properties of the working medium chosen for modeling R134a, empirical equations from the works of Kabelec and Cleland [24] were used as the most adapted for computer calculations.

Saturation pressure by saturation temperature

$$p_{sat} = \exp\left(21{,}51297 - \frac{2200{,}9809}{246{,}61 + t_{sat}}\right). \quad (2.1)$$

Saturation temperature saturation pressure

$$t_{sat} = \left(\frac{-2200{,}9809}{\ln(p_{sat}) - 21{,}51297}\right) - 246{,}61, \quad (2.2)$$

where t_{sat} is the saturation temperature ^{o}C ,; p_{sat} - t isk of saturation, *Pa*.

The enthalpy of a saturated or supercooled liquid depends on its temperature, moreover

$$\Delta t_{в} = t_{sat} - t_L, \quad (2.3)$$

where $\Delta t_{в}$ is the degree of supercooling of a saturated liquid, *degrees*;

t_L - temperature of supercooled liquid, ^{o}C .

Provided that $\Delta t_{в} \geq 0$, the enthalpy will be

$$h_L = 200000 + 1335{,}29\,t_L + 1{,}70650\,t_L^2 + 7{,}6741 \cdot 10^{-3} t_L^3, \quad (2.4)$$

where h_L = 200,000 *J/kg* at 0 ^{o}C .

The enthalpy of saturated steam is described by a polynomial dependence

$$h_{i1} = 249455 + 606{,}163\,t_{sat} - 1{,}05644\,t_{sat}^2 - 1{,}82426 \cdot 10^{-2} t_{sat}^3; \quad (2.5)$$

$$h_V = h_{i1} + 149048,\ J/kg. \quad (2.6)$$

The enthalpy of superheated steam is calculated using a polynomial equation depending on the amount of steam superheat

$$\Delta t_s = t_s - t_{sat}, \quad (2.7)$$

where Δt_s - The amount of steam overheating, *degrees* ; t_s - Temperature of superheated steam, ^{o}C .

Then the enthalpy:

$$h_{i2} = h_{i1}(1 + 3{,}48186 \cdot 10^{-3}\Delta t_s + 1{,}6886 \cdot 10^{-6}\Delta t_s^2 + 9{,}2642 \cdot 10^{-6}\Delta t_s t_{sat} -$$

$$- 7{,}698 \cdot 10^{-8}\Delta t_s^2 t_{sat} + 1{,}7070 \cdot 10^{-7}\Delta t_s t_{sat}^2 - 1{,}2130 \cdot 10^{-9}\Delta t_s^2 t_{sat}^2); \quad (2.9)$$

$$h_s = h_{i2} + 149048\ ,\ J/kg. \quad (2.9)$$

The specific amount of steam on the saturation line is described by the following polynomial:

$$v_V = \exp\left(-12{,}4539 + \frac{2669{,}0}{273{,}15 + t_{sat}}\right)(1{,}01357 + 1{,}06736 \cdot 10^{-3} t_{sat} -$$

$$- 9{,}2532 \cdot 10^{-6} t_{sat}^2 - 3{,}2192 \cdot 10^{-7} t_{sat}^3), \text{ м}^3/\text{кг}. \quad (2.11)$$

The specific amount of superheated steam is calculated using the following polynomial depending on the amount of superheated steam Δt_s (see equation 2.7):

$$v_s = v_V (1 + 4{,}7881 \cdot 10^{-3} \Delta t_s - 3{,}965 \cdot 10^{-6} \Delta t_s^2 + 2{,}5817 \cdot 10^{-5} \Delta t_s t_{sat} -$$

$$- 1{,}8506 \cdot 10^{-7} \Delta t_s^2 t_{sat} + 8{,}5739 \cdot 10^{-7} \Delta t_s t_{sat}^2 - 5{,}401 \cdot 10^{-9} \Delta t_s^2 t_{sat}^2), \text{ м}^3/\text{кг}. \quad (2.12)$$

Enthalpy difference during adiabatic (isentropic) compression of steam in a compressor without overheating

$$\Delta h = \frac{c}{c-1} p_1 v_1 \left[\left(\frac{p_2}{p_1}\right)^{\frac{c-1}{c}} - 1\right], \text{ Дж/кг}, \quad (2.1\ 1)$$

where p_1 - t is suction, Pa ; p_2 - t injection pressure, Pa ;

v_1 – specific volume of steam at suction $\text{м}^3/\text{кг}$ (see (2. 09);

c - n exponent of compression polytropy.

When calculating the index of compression polytropy, the difference in saturation temperatures is taken into account

$$\Delta t_c = t_{sat2} - t_{sat1}, \ city\_ \quad (2.12)$$

Then

$$c_{i1} = 1{,}06469 - 1{,}6907 \cdot 10^{-3} t_{sat1} - 8{,}560 \cdot 10^{-6} t_{sat1}^2 - 2{,}135 \cdot 10^{-5} t_{sat1} \Delta t_c -$$

$$- 6{,}1730 \cdot 10^{-7} t_{sat1}^2 \Delta t_c + 2{,}0740 \cdot 10^{-7} t_{sat1} \Delta t_c^2 + 7{,}720 \cdot 10^{-9} t_{sat1}^2 \Delta t_c^2 -$$

$$- 6{,}103 \cdot 10^{-4} \Delta t_c; \quad (2.15)$$

$$c = c_{i1}.$$

The difference in enthalpies during isentropic compression of steam in the compressor, taking into account their overheating on suction, is determined by equation (2.11).

The index of compression polytropy is preliminarily calculated, taking into account the amount of steam overheating Δt_s, as in equation (2.6)

$$c = c_{i1}(1 + 1{,}1757 \cdot 10^{-3} \Delta t_s - 1{,}814 \cdot 10^{-5} \Delta t_s^2 + 4{,}121 \cdot 10^{-5} \Delta t_s t_{sat1} -$$

$$- 8{,}093 \cdot 10^{-7} \Delta t_s^2 t_{sat1}), \quad (2.16)$$

where c_{i1} - from the equation (2.12).

The entropy of the working body, depending on its temperature and density, can be generally calculated as follows:

$$S(T, v) = S_o + \int_{T_o}^{T} c_v^0(T) \frac{dT}{T} + \int_{\infty}^{v} \left[\left(\frac{\partial p}{\partial T}\right)_v - \frac{R}{v}\right] dv + R \ln\left(\frac{v}{v_o}\right), \quad (2.1\ 4)$$

where $$c_v^0(T) = C_p^0(T) - R \qquad (2.15)$$

The entropy of a saturated and superheated R134a vapor can be determined by the following empirical equation [16]:

$$S(T_r, v_V) = 0{,}7808 + (c_1 - 0{,}081489)\ln T_r + c_2 T_r + \frac{c_3}{2}T_r^2 + 0{,}081489 \ln v_V + \frac{1}{T_{cr}} \times$$

$$\times \left\{ \frac{1}{6}\frac{B}{T_r^{8/3} v_V} - \frac{1}{20}\left[C_1 - 3{,}2C_2 \exp(-3{,}2T_r)\right]\frac{1}{v_V^2} + \frac{1}{45}\frac{D}{T_r^{5/3} v_V^3} \right\}, кДж/(кг \cdot K), \quad (2.19)$$

where $T_r = \frac{T}{T_c}$ is the specified temperature; T_c=374.205^oK – critical temperature R 134 a ; c_1=0.19014; c_2=0.94817; c_3=-0.177953; B= -821.538; D= -274.861; C_1=318,032; C_2=14052.44; v_V - p ith volume of saturated steam, $дм^3/кг$; S_o=1.00 *kJ/(kg K)* for 0°C.

The entropy of a saturated liquid is defined as follows:

$$S'_L(T_r) = S(T_r, v''_V) - \frac{1}{10}\left[v''_V(T_r, p_s) - v'_L(T_r)\right]\frac{1}{T_c}\frac{dp_s}{dT_r}, \qquad (2.16)$$

where $$\frac{dp_s}{dT_r} = -p_s(T_r)\left[\frac{a_1}{T_r^2} + a_2\frac{(1-T_r)^{1/3}}{T_r}\left(\frac{1}{3} + \frac{1}{T_r}\right) + a_3\frac{(1-T_r)^2}{T_r}\left(2 + \frac{1}{T_r}\right)\right], \quad (2.17)$$

where a_1= -7.7842; a_2=1.4040; a_3= -3.11419.

To determine the entropy in the two-phase region, the author developed a polynomial equation by approximating the array of tabular data by the least squares method, which, depending on the enthalpy and saturation temperature in the regions t_s =–30...95 °C and h=160...350 *kJ/kg,* allows obtaining the entropy value with a maximum error of up to ±0.001 *kJ/(kg ·K)* :

$$S = (F_{11}t_s^2 + F_{12}t_s + F_{13})h + F_{14}t_s + F_{15}, кДж/(кг \cdot K), \qquad (2.18)$$

where $F_{11} = 0{,}4464 \cdot 10^{-7}$ $F_{12} = -13{,}512 \cdot 10^{-6}$; $F_{13} = 36{,}7 \cdot 10^{-4}$;

$F_{14} = 0{,}262 \cdot 10^{-2}$; $F_{15} = 0{,}265$.

It is also important to correctly determine the parameters at the end of the isentropic compressor compression process. The author proposed such an analytical method.

Fig. 8 shows a simplified representation of the isentropic compression process in compressor 1–2. The amount of compression work in the case is determined as:

$$l_{ad} = \Delta h = h_2 - h_1, \qquad (2.19)$$

from where $$h_2 = h_1 + \Delta h \qquad (2.20)$$

It also compresses work l_{ad} can be determined analytically by equation (2.9), then

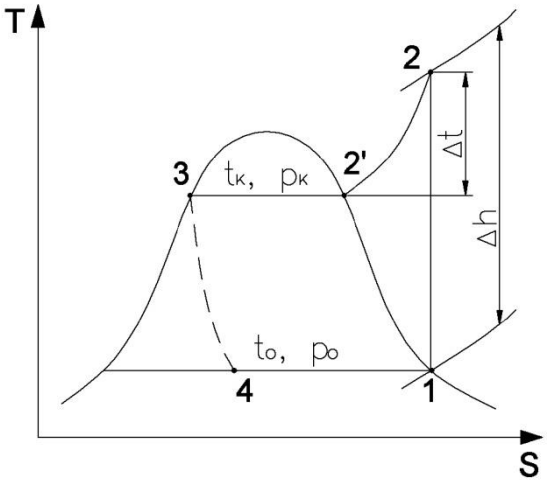

Fig. 8. Determining the temperature at the end of compressor compression

$$h_2 = h_1 + \frac{c}{c-1} p_1 v_1 \left[\left(\frac{p_2}{p_1} \right)^{\frac{c-1}{c}} - 1 \right]. \qquad (2.21)$$

In equation (2.21), all parameters are known, except for the index of compression polytropy c, which is calculated using equations (2.11) or (2.10). Now solving equation (2.19) , taking into account the parameters of equations 2.11) or (2.12), with respect to Δt we get:

$$\Delta t_{1,2} = -\frac{1}{2}\frac{A}{B} \pm \sqrt{\left(\frac{1}{2}\frac{A}{B}\right)^2 - \frac{C - h_2 + 149048}{CB}}, \qquad (2.22)$$

where

$$3{,}48186 \cdot 10^{-3} + 9{,}2642 \cdot 10^{-6} t_{sat} + 1{,}7070 \cdot 10^{-7} t_{sat}^2 = A; \qquad (2.23$$

$$1{,}6886 \cdot 10^{-6} - 7{,}698 \cdot 10^{-8} t_{sat} - 1{,}2130 \cdot 10^{-9} t_{sat}^2 = B; \qquad (2.24)$$

$$249455 + 606{,}163\, t_{sat} - 1{,}05644\, t_{sat}^2 - 1{,}82426 \cdot 10^{-2} t_{sat}^3 = C. \quad (2.2\ 5)$$

The real root Δt must meet the conditions: $0 \le \Delta t < t_c$.

Another root has no physical meaning.

And, in the end, the temperature after isentropic compression in the compressor will be determined as:

$$t_2 = t_{sat2} + \Delta t, \ ^\circ C. \qquad (2.\ 6)$$

Determination of the final temperature of the working body after the compressor during the polytropic compression process taking into account the adiabatic (isentropic) efficiency. is carried out in a similar way. At the same time, it is important to correctly define first $h_2,\ p_2, t_{sat2}, v_{sat2}$:

It is also important to correctly determine the parameters at the point of the cycle after subcooling the liquid working medium in an industrial refrigerator or a regenerative heat exchanger.

The enthalpy at point 3' is determined from the heat balance of RTO:

$$h_{3'} = h_3 - \left(h_{1'} - h_1\right), J/kg. \qquad (2.\ 27\ )$$

Also, the enthalpy at point 3' can be calculated using equation (2.4). Solving the equation (2.4) with respect to the temperature t_L taking into account h_L, neglecting, at the same time, the fourth term of this equation as an infinitesimally small value, which is approximately 0.004% compared to the smallest third term, we obtain:

$$t_{L1,2} = -\frac{1}{2}\left(\frac{1335,29}{1,7065}\right) \pm \sqrt{\left[\frac{1}{2}\left(\frac{1335,29}{1,7065}\right)\right]^2 - \frac{200000 - h_L}{1,7065}}. \qquad (2.28)$$

The real root of this equation must meet the conditions: $t_o < t_L \le t_к$. Another root has no physical meaning.

To determine this temperature, the author also developed the following polynomial equation with a determination error of ±0.05 $^{\circ}C$ in the temperature range of saturated and supercooled working fluid (–30...95) $^{\circ}C$ and enthalpies (160...350) *kJ/kg*

$$t_s = B_5 h_L^2 + B_6 h_L + B_7, \ ^{\circ}C \qquad (2.29)$$

where $B_5 = -10,3675 \cdot 10^{-4}$_ $B_6 = 1,1942$; $B_7 = -197,151$.

2.3.3. Module "Thermophysical properties of R 134a"

Density of the liquid working medium [24]

$$\rho_R = 1 + C_1(1 - T_R)^{1/3} + C_2(1 - T_R)^{2/3} + C_3(1 - T_R) + C_4(1 - T_R)^{4/3}, \ (2.55)$$

where $\rho_R = \frac{\rho_{ж}}{\rho_c}$, $кг/м^3$ - The given density; $\rho_c = 515,3$,$кг/м^3$ - Critical density R 134a [28,29,36]; $T_R = \frac{\overline{T}_{ж}}{T_{cr}}$ - The specified temperature; $T_{cr} = 374,205\ ^{o}K$ - Critical temperature R 134a [26 , 27 , 29]; $C_1 = 1,7127$; $C_2 = 1,045143$; $C_3 = –0,2276586$; $C_4 = 0,1836428$ - coefficients.

$$\rho'_{ж} = \rho'_R \cdot \rho_c, \ кг/м^3. \qquad (2.56)$$

Specific heat capacity of liquid, *kJ/(kg K)* [29]

$$c_{pж} = M_o + M_1(1 - T_R)^{1/9} + M_2(1 - T_R)^{2/9} + M_3(1 - T_R)^{3/9} + M_4(1 - T_R)^{6/9}, \qquad (2.57)$$

where $M_o = 395,19033$; $M_1 = -1588,637$; $M_2 = 2233,8111$; $M_3 = -1120,361$; $M_4 = 81,256634$.

The coefficient of thermal conductivity of the liquid [29]

$$\lambda_{ж} = j_o + j_1 t, \ W/(m \cdot K), \qquad (2.58)$$

where $j_o = 94,21 \cdot 10^{-3}$_ $j_1 = –0,42784 \cdot 10^{-3}$.

Coefficient of dynamic viscosity of liquid [29]

$$\ln\left(\frac{\eta_{ж}}{10^{-3}}\right) = H_o + H_1 t + H_2 t^2 + H_3 t^3, \ Pa \cdot s, \qquad (2.59)$$

where $H_o = -1{,}29909$; $H_1 = -0{,}0129286$; $H_2 = 4{,}9223 \cdot 10^{-6}$; $H_3 = -1{,}9860 \cdot 10^{-7}$.

Coefficient of thermal conductivity of a vaporous working fluid [29]

$$\lambda_{П} \cdot 10^3 = L_o + L_1 t + L_2 t^2 + L_3 t^3 + L_4 t^4, \; W/(m \cdot K) \qquad (2.60)$$

where $L_o = 11{,}84$; $L_1 = 0{,}08305$; $L_2 = 1{,}33741 \cdot 10^{-4}$; $L_3 = 0$; $L_4 = 0$.

Coefficient of dynamic vapor viscosity [29]

$$\eta_{П} \cdot 10^6 = \frac{1}{\zeta \cdot 10^{-5} \sum_{n=0}^{3} I_n \left(\frac{T}{T_c} \right)^n}, \; Pa \cdot s, \qquad (2.61)$$

where $\zeta = 39721{,}0 \left(Па \cdot с \right)^{-1}$;

$$\zeta = \frac{N_o^{1/3} \left(T_c \cdot R \right)^{1{,}6}}{M^{1/2} \cdot P_c^{2/3}}; \qquad (2.62)$$

where $N_o = 6{,}023 \cdot 10^{26}$ $кмоль^{-1}$is Avogadro's number; $R = 8{,}314$ $кДж/\left(кмоль \cdot К \right)$- Universal gas constant; $M = 102{,}032$ $кДж / кмоль$ – molecular weight R 134a; $P_c = 4060000$ $Н / м^2$- Critical pressure R 134a; $I_o = 4{,}378104 \cdot 10^{-1}$; $I_1 = -3{,}8781499 \cdot 10^{-1}$; $I_2 = 3{,}7866105 \cdot 10^{-1}$; $I_3 = -3{,}29657 \cdot 10^{-3}$.

Specific heat capacity of a vaporous working fluid [29]

$$c_{p_{П}} = D_1 + D_2 t + D_3 t^2 + D_4 t^3 + \frac{D_5}{t}; \; kJ/(kg \; K), \qquad (2.63)$$

where $D_1 = -5{,}257455 \cdot 10^{-3}$; $D_2 = 3{,}29657 \cdot 10^{-3}$;

$D_3 = -2{,}017321 \cdot 10^{-6}$; $D_4 = 0$; $D_5 = 15{,}8217$.

Density of the vaporous working fluid [23]

$$\frac{1}{\rho_{s_{П}}} = \frac{1}{\rho_{V_{П}}} (1 + 4{,}7881 \cdot 10^{-3} \Delta t_s - 3{,}965 \cdot 10^{-6} \Delta t_s^2 + 2{,}5817 \cdot 10^{-5} \Delta t_s t_o -$$

$$-1{,}8506 \cdot 10^{-7} \Delta t_s^2 t_o + 8{,}5739 \cdot 10^{-7} \Delta t_s t_o^2 - 5{,}401 \cdot 10^{-9} \Delta t_s^2 t_o^2), \; м^3 / кг, \qquad (2.64)$$

where $\Delta t_s = \bar{t}_{П} - t_o$, ^oC; t_o - t boiling temperature in the cycle, ^oC;

$$\frac{1}{\rho_{V_{П}}} = \exp \left(-12{,}4539 + \frac{2669{,}0}{273{,}15 + t_o} \right) \times$$

$$\times (1{,}01357 + 1{,}06736 \cdot 10^{-3} t_o - 9{,}2532 \cdot 10^{-6} t_o^2 - 3{,}2192 \cdot 10^{-7} t_o^3), \; м^3 / кг. \qquad (2.65)$$

2.4. Formation of modules of the fourth level

2.4.1. Module "Piston steam compressor"

In R M, compressors are designed to compress and move gas or steam of

working bodies.

According to the principle of action, compressors are divided into two groups: volumetric action (piston, screw, various rotary and others) and dynamic action (centrifugal, axial and others). Reciprocating compressors have become the most widely used for installations of various performance.

The formed model of the piston compressor must take into account the factors that affect the operation of a real compressor in contrast to a theoretical one. The influence of many factors affects the actual working processes of the compressor, including the following main ones: 1) presence of dead space; 2) hydraulic losses in the suction and discharge cavities; 3) steam heating on the suction line; 4) heat exchange in the cylinder during compression and reverse expansion; 5) pressure pulsation; 6) leakage through gaps, leaks and piston ring locks; 7) friction in mechanical elements.

Real work processes are noticeably different from theoretical ones. The suction process occurs at a variable pressure lower than the pressure in the suction pipe. The difference in pressure in the nozzle and at the beginning of compression is called suction depression. The injection process takes place under variable pressure. The difference between the final pressure in the cylinder and at the outlet of the compressor is called the compression pressure. The most important factor is the actual performance and capacity of the compressor. The main indicator of the decrease in actual productivity V_{∂} compared to the theoretical V_T one is the feed rate λ

$$V_{\partial} = \lambda \cdot V_T . \tag{2.66}$$

Compressor delivery ratio

$$\lambda = \lambda_c \lambda_{\partial p} \lambda_w \lambda_{n\pi} . \tag{2.67}$$

The operation of the compressor with valid processes of compression, discharge, reverse expansion and suction corresponds to the indicator power N_i, which is determined by the valid indicator diagram

$$N_i = p_i \cdot V_T , \tag{2.68}$$

where p_i is the average indicator pressure.

The isentropic (adiabatic) capacity of the compressor evaluates the energy efficiency of all its actual working processes.

$$N_{a\partial} = G_{a\partial} \cdot l_{a\partial} = \frac{\lambda V_T l_{a\partial}}{v_1} , \tag{2.69}$$

and the effective power is supplied to the compressor shaft N_e.

The compressor module of a single-stage installation can be provided as a structural model shown in Fig. 9a.

Structural models of compressor modules I and II stages of the two-stage installation are shown in Fig. 9b and 9c, respectively.

2.4.2. Module "Screw oil-filled steam compressor

When conducting a thermal calculation of an oil-filled screw

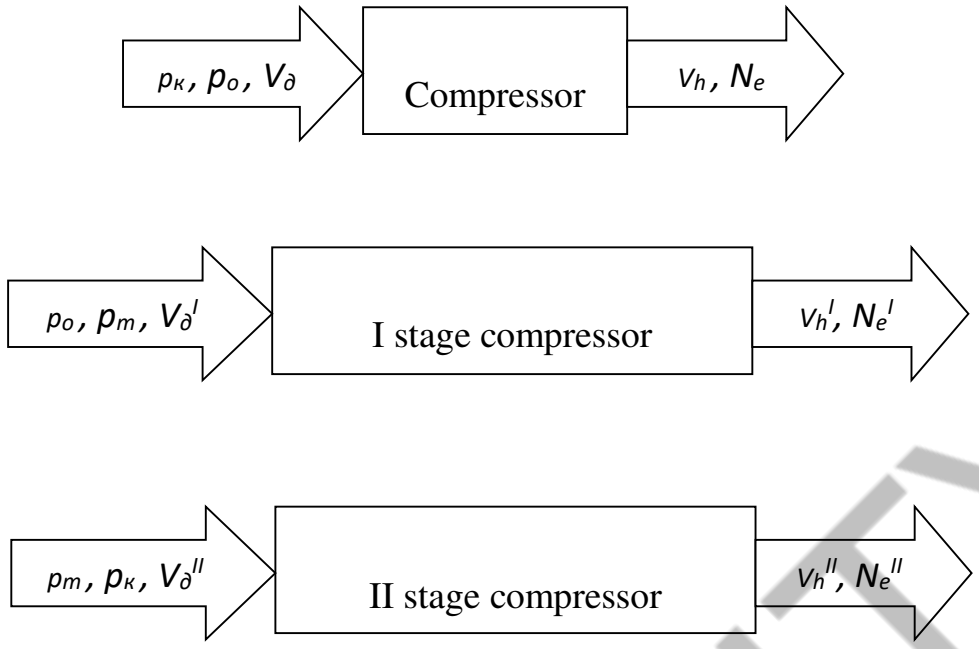

Fig. 9. Structural diagram of the compressor model

output parameters are set for the spring compressor as for the piston compressor. At the same time, the corresponding modules of the second and third levels are initiated.

The actual volumetric productivity is determined $V_д$.

Theoretical volume performance of the compressor:

$$V_h = \frac{V_д}{\lambda}, м^3 / с,$$

where λ - the supply coefficient of the oil-filled screw compressor, which, depending on the degree of compression $\pi_к$, can be determined analytically according to the generalized data (at $2 \le \pi_к \le 18$):

$$\pi_к = \frac{p_2}{p_1}; \qquad \lambda = -0{,}0188\pi_к + 0{,}914, \qquad (2.70)$$

All other parameters are identical to the parameters of the piston compressor.

2.4.3. "Condenser" module

The condenser is one of the main heat exchange devices in R M. Liquids and gases are used as coolants for condensers.

most often used in R M, in which the coolant (water) is passed inside the pipes, and the working fluid is condensed on the outside of the pipes in the inter-pipe space. On the basis of the above, a model of the shell-and-tube structure of the condenser with the cooling medium - water was formed. For this, the initial data are pre-set: geometric and design parameters of the heat exchange element of the condenser - the tube. A fragment of the tube with the main geometric dimensions is shown in Fig. 13. Modeling of heat exchange elements of any standard size is possible.

The outputs used in this module are identified in the first and second level modules: G_a, $Q_к$, $t_к$, t_{w_1}, t_{w_2}.

The capacitor is calculated according to known methods.

hydromechanical calculation of the capacitor forms the basis of the modules of the seventh level.

The structural model of the capacitor module is shown in Fig. 10.

2.4.4. "Evaporator" module

In R M, the evaporator is one of the main heat exchange devices and is designed to remove heat at low temperature from the environment or from the coolant. Water and water-salt solutions based on brine $NaCl$ are mainly used as heat carriers $CaCl_2$.

Most often in R M, shell-and-tube evaporators of the submerged type are used, inside the pipes of which the coolant passes, and the working medium boils inside the casing of the device, cooling the coolant at the same time.

Let's create a model of a flooded shell-and-tube evaporator with boiling of the working fluid in the intertube space.

Initial parameters from the modules of the first and second levels are pre-entered: Q_o, G_a, t_o, t_{s1}, t_{s2}. The design characteristics of the heat exchange element of the evaporator - the tube - are also pre-set (the same tubes are used in submerged shell-and-tube evaporators as in submerged shell-and-tube condensers). The choice is made based on the data of the modules of the fifth level. An aqueous solution of calcined salt ($CaCl_2$) with a composition of 23.8 *kg/kg was chosen as the heat carrier.* Its thermophysical properties depend on the average temperature $\bar{t}_s$ in the form of appropriate modules presented in the sixth level.

transfer coefficient

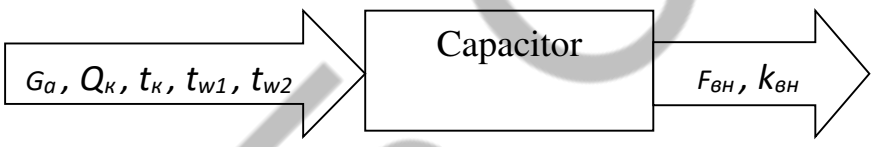

Fig. 10. Structural diagram of the capacitor model

and the size of the heat exchange surface of the evaporator is carried out in the same way as for the condenser (clause 2.4.3).

The hydromechanical calculation of the evaporator forms the basis of the modules of the seventh level.

The structural model of the evaporator module is shown in Fig. 11.

2.4.5. Module "Regenerative heat exchanger"

PTOs belong to R M auxiliary devices. In them, heat exchange takes place between the liquid working fluid that enters the throttle valve after the condenser, and the vapor-like agent that leaves the evaporator. For modeling, a vertical type of shell-and-tube RTO, which has the largest heat exchange surface, was chosen.

The initial data for modeling are modules of the first and second levels, as well as:

- heat load RTO, Q_{PTO}, kW;
- the temperature of the liquid working medium at the entrance to the RTO, $t_{ж1}$, ^oC;

- the temperature of the supercooled liquid working fluid at the outlet of the RTO, $t_{ж2}$, ^{o}C;

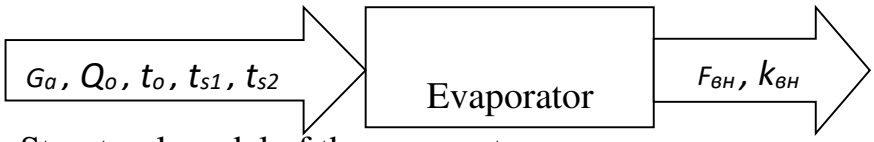

Fig. 11. Structural model of the evaporator

- the temperature of the saturated vapor of the working medium at the entrance to the RTO, $t_{п1}$, ^{o}C;
- the temperature of the superheated vapor of the working medium at the outlet of the RTO, $t_{п2}$, ^{o}C.

The main structural dimensions characterizing the heat transfer surface of the device are set: heat exchange elements - copper tubes, smooth; $d_{вн}$ - Inner diameter of the tube; $d_{н}$ - Outer diameter of the tube; n - Number of tubes connected in parallel; $D_{б}$ - The outer diameter of the core (displacer), on which the heat exchange tubes are wound; m – the number of winding rows; S_1 - The distance between adjacent rows along the center of the pipes; S - The thickness of the distance plates. Along the core, the tubes are wound without a gap.

Thermophysical properties of refrigerants at their average temperatures are determined using modules of the third level.

Calculation of RTO is carried out according to known methods.

Hydraulic calculations of RTO in the pipe and inter-pipe space are carried out with the help of the corresponding modules of the seventh level.

The structural model of the regenerative heat exchanger module is shown in Fig. 12.

2.5. Formation of modules of the fifth level

Modules of the fifth level are a description of the geometric and design parameters of the heat exchange elements of the main and auxiliary devices [21, 24, 27, 29], as well as a formalized series of pipes

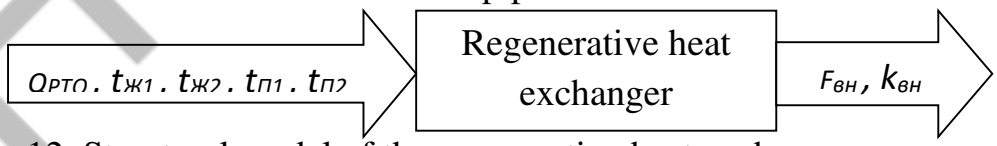

Fig. 12. Structural model of the regenerative heat exchanger

for the etiquette of RTO.

2.5.1. Module "Heat exchange tubes"

The main geometric parameters of the heat exchange tube are shown in Fig. 13. Conventional designations of tube parameters are as follows:

$d_{вн}$ - Inner diameter of the pipe, m; d_{o} - Diameter of the pipe along the circumference of the depressions, m; $d_{н}$ - Diameter of the pipe around the protrusions, m; S_p - Rib

step, m ; $F'_н$ - Outer surface, $м^2 / м$; $F'_{вн}$ - Inner surface, $м^2 / м$; $\varphi = F'_н / F'_{вн}$ - Rib coefficient; δ_p - Rib thickness, m ; h_p - Rib height, m ; $h_p = \frac{d_н - d_o}{2}$; λ_p - Coefficient of thermal conductivity of the rib, *W / (m K).*

According to the above designations, the size range of heat exchange tubes is integrated into the TT – RH modular system.

2.5.2. The module "Pipes for communication to RTO ".

Hot-rolled seamless steel pipes (D ST U 8732-70).

Depending on the purpose, the pipes are supplied in groups (D ST U 8731-66). The standard size of the corresponding pipes for the PTO promises is integrated into the TT - RH modular system.

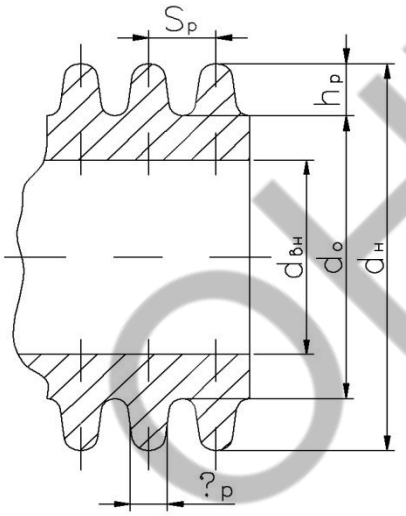

Fig. 13. The main geometric parameters of the heat exchange tube

2.6. Formation of modules of the sixth level

The modules of the sixth level include the thermophysical properties of coolants used in the main R M devices: water and brine (of different chemical composition), as well as dry air (as a coolant for an air condenser). For better algorithmization of the model on the computer, all thermophysical properties of the coolant were processed by the method of least squares and presented in an analytical form.

2.6.1. Module "Thermophysical properties of water"

Heat carrier: water. Temperature range $0...100\,^oC$ [3,5].

Heat capacity, *kJ/(kg ·K)*

$$c_{pw} = 0{,}1647 \cdot 10^{-4} t_w^2 - 0{,}1488 \cdot 10^{-2} t_w + 4{,}212. \qquad (2.7\,0)$$

Density , $кг / м^3$

$$\rho_w = -0{,}356 \cdot 10^{-2} t_w^2 - 7{,}09 \cdot 10^{-2} t_w + 999{,}9. \qquad (2.71)$$

Coefficient of kinematic viscosity, $м^2 / c$

$$v_w \cdot 10^6 = 0{,}1931 \cdot 10^{-3} t_w^2 - 3{,}229 \cdot 10^{-2} t_w + 1{,}682. \quad (2.72)$$

Prandtl number

$$\mathrm{Pr}_{жw} = 0{,}1623 \cdot 10^{-2} t_w^2 - 0{,}263\, t_w + 12{,}409. \quad (2.73)$$

Thermal conductivity coefficient, *W/(m ·K)*

$$\lambda_w = -0{,}708 \cdot 10^{-5} t_w^2 + 0{,}1929 \cdot 10^{-2} t_w + 0{,}561. \quad (2.74)$$

2.6.2. Module "Thermophysical properties of an aqueous solution $CaCl_2$"

The heat capacity of the brine $CaCl_2$ composition is 23.8 *kg/kg* depending on $\bar{t}_s$ [22]:

$$c_s = 4{,}1868\,[c_o + 0{,}19 \cdot 10^{-2} \bar{t}_s (\sqrt[4]{1 - \lambda_{15}} - 0{,}409)],\ KJ/(kg\ \cdot K), \quad (2.75)$$

where c_o=0.7 *kcal/kg ·degrees* – the heat capacity of brine of the specified composition at $0\,^oC$;

λ_{15}=0.558 *W/m K* is the thermal conductivity of brine of the specified composition at $15\,^oC$.

The values of the densities of the brine of the specified composition, depending on the temperature $\bar{t}_s$, as well as other thermophysical properties λ_s, v_s, and Pr_s were processed by the method of least squares and presented in an analytical form:

$$\rho_s = 0{,}6264 \cdot 10^{-2} \bar{t}_s^2 - 0{,}4382\, \bar{t}_s + 1227,\ кг/м^3. \quad (2.7\ 6)$$

Thermal conductivity coefficient of brine

$$\lambda_s = -0{,}1904 \cdot 10^{-5} \bar{t}_s^2 + 0{,}1381 \cdot 10^{-2} \bar{t}_s + 0{,}5383,\ W/m\ To. \quad (2.77)$$

Coefficient of kinematic viscosity of brine

$$v_s \cdot 10^6 = 0{,}5032 \cdot 10^{-2} \bar{t}_s^2 - 0{,}1319\, \bar{t}_s + 3{,}1222,\ м^2/с. \quad (2.78)$$

Prandtl number of brine

$$\mathrm{Pr}_{жs} = 0{,}0527\, \bar{t}_s^2 - 1{,}0129\, \bar{t}_s + 21{,}2. \quad (2.79)$$

If necessary, you can generate the indicated properties of brine based on $CaCl_2$ any composition, depending on $\bar{t}_s$ and, after appropriate processing, obtain generalized dependences of thermophysical properties, depending on the composition of the brine and its temperature:

$$c_s, \rho_s, v_s, \lambda_s, \mathrm{Pr}_{жs} = f(\xi, \bar{t}_s).$$

2.6.3. Module "Thermophysical properties of air"

Air temperature range (-30... 50) ^oC [3,5].

Air density

$$\rho = 0{,}1583 \cdot 10^{-4} t^2 - 0{,}475 \cdot 10^{-2} t + 1{,}2932, \quad кг/м^3. \quad (2.81)$$

Coefficient of kinematic air viscosity

$$\nu \cdot 10^6 = 0{,}249 \cdot 10^{-3} t^2 + 0{,}8227 \cdot 10^{-1} t + 13{,}2929, \quad м^2/с. \quad (2.82)$$

Coefficient of thermal conductivity of air

$$\lambda \cdot 10^2 = 0{,}83 \cdot 10^{-5} t^2 + 0{,}7724 \cdot 10^{-2} t + 2{,}4343, \quad Bm/(м \cdot K). \tag{2.83}$$

Heat capacity of air in the temperature range $(-20...-1)^o C$

$$c_p = 1{,}009, \quad кДж/(кг \cdot K). \tag{2.84}$$

Heat capacity of air in the temperature range $(0...60)^o C$

$$c_p = 1{,}005, \quad кДж/(кг \cdot K). \tag{2.85}$$

2.7. Formation of modules of the seventh level

2.7.1. Module "Hydromechanical calculation of condenser, evaporator, regenerative heat exchanger"

The hydromechanical calculation of the condenser , evaporator, and regenerative heat exchanger is based on the determination of pressure losses due to hydro- and aerodynamic resistances that occur during the movement of working media in the heat exchanger.

2.8. Formation of modules of the eighth level

Modules of the eighth level are catalogs of the main functional elements of RM: compressors, condensers, evaporators and PTO. These modules are autonomous under the conditions of operation of the TT- RH dialogue system. They can be accessed by modules of the ninth level in order to generate the composition RM for the specified operating conditions. The composition of the modules of the eighth level is as follows.

1. Unified range of piston compressors (OST26.03-943-77) [20,21]. The selection criteria are: the volume described by the pistons V_h , $м^3 / c$ and the limit pressure difference $(p_к - p_о)$, *MPa.*
2. Horizontal shell-and-tube condensers of cold air [18,19]. The selection criterion is: the area of the heat transfer surface (internal) $F_{вн}$, $м^2$.
3. Evaporators are shell-and-tube horizontal khladon submerged type [18,19]. The selection criterion is: the area of the heat transfer surface (internal) $F_{вн}$, $м^2$.
4. Regenerative refrigerant heat exchangers [18,19]. The selection criterion is: the area of the heat transfer surface (internal) $F_{вн}$, $м^2$.

The parametric series of the relevant industrial equipment are integrated into the TT–RH modular system.

3. CONCLUSIONS ON THE WORK

conclusions can be drawn from the conducted research :

1. an open universal multi-level modular system TT–RH was developed for the formation of thermotechnical models of thermotransformers operating according to the combined RH scheme ;
2. the developed TT-RH system allows generating heat engineering models RM of

arbitrary schemes; calculate the characteristics under the given conditions of changing the parameters; document the results of calculations, store reference and other information;

3. for calculations of thermodynamic and thermophysical properties of R134a, R717, $CaCl_2$, water and air under appropriate conditions, approximation dependencies were developed.

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INTELLIGENT CONTROL SYSTEM OF GREENHOUSE MICROCLIMATE PARAMETERS

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Abstract. *An important role in the formation of vegetable harvest in the greenhouse is played by its microclimate. However, existing systems of its provision in greenhouse structures have major disadvantages: temperature is not taken into account on the surface of plants; temperature differences from unreliable factors such as solar radiation, outside temperature and other outside changes, are not evaluated comprehensively. Therefore, conducting research aimed at developing methods, techniques and information-software tools for automating the control of microclimate parameters in the greenhouse is an urgent task. Based on the results of research, there have been conducted structural and fundamental schemes, algorithmic, informational guarantee of work for automated systems that manage parameters of microclimate in greenhouses.*

Keywords: *automated control system, greenhouse microclimate, neural networks, adaptive control system.*

I. INTRODUCTION

Meeting the needs of the Ukrainian population in vegetables during autumn, winter and spring requires the use of closed soil agricultural technologies. Since these technologies require significant energy costs (the agro-industrial complex of Ukraine consumes about 20 percent of energy resources, the cost of which is steadily increasing), a significant increase in the energy efficiency of technological processes in the cultivation of vegetables for domestic farmers is urgent.

The microclimate of the room and lighting of the plants play a decisive role in the formation of a crop of vegetables of excellent quality in the greenhouse. During dynamic modes of operation of the greenhouse, the values of temperature, humidity, illumination and the level of carbon dioxide in it significantly deviate from the optimal values.

The transfer of greenhouse farms to an industrial basis with the use of modern automatic systems for controlling microclimate parameters is the key to sustainable supply of vegetables to the population in the climatic conditions of Ukraine in the required quantity and high quality.

Existing systems for ensuring optimal parameters of the microclimate in greenhouses have a number of shortcomings - the temperature on the surface of plants is not taken into account, the influence of solar radiation is not comprehensively evaluated, the change in temperature and speed of movement of external air flows, the material and construction of the fence, as well as other factors that have random nature.

II. LITERATURE ANALYSIS

Significant value in the cultivation of vegetables in greenhouses have processes of automatic control and support of parameters of the microclimate, which determine

the growth and development of plants in certain cultures. Not enough studies have been done in terms of research and development of automated parameter control systems of microclimates capable to work in greenhouses. Definition of basic adjustable parameters of microclimate in greenhouses, which affect growth and development of vegetables; comparative analysis of modern automated control systems in the greenhouse from the point of view of their energy efficiency and upkeeping of agrotechnical requirements is an important question.

2.1. Development of technologies for growing vegetables in enclosed soil

The vegetable market of Ukraine in the winter and spring periods of the year is provided as per account of enclosed soil structures, and at the expense of import vegetables.

To meet the needs of the Ukrainian population in vegetables it's in best of interests to expand domestic greenhouses. Lots of work is dedicated to the question of constructive and thermophysical characteristics of greenhouses.

To increase efficiency of vegetable growth in enclosed soil there are actively implemented promising energy and resource-saving technologies for growing vegetables with automatic support systems of microclimate modes. With this productivity reaches 35...40 kg of vegetables within 1 m^2, and with the usage of microclimate control system technologies and methods of plant growth stimulation, the harvest amounts significantly rise.

It is established that lack of automated management systems for maintenance of optimal climatic conditions in enclosed construction leads to overspending on energy carriers, reduction of harvest from different vegetable crops. Highest costs of energy carriers for heating greenhouses has been observed in December - February, when the air temperature descends below -10 °C. Solutions for establishing optimal microclimatic conditions at minimum energy consumption through software, despite a constant growth in energy prices, is an urgent scientific and technical task, the solution of which leads to an increase in profitability of vegetable products production.

These questions are solved through improvement of greenhouse structures, increasing the efficiency of heat sources for heating the coolant, as well as improving methods and principles for development of control systems microclimate.

A choice of control method for microclimate in greenhouses is determined, first of all, by the nature of disturbances to object management, its reaction to such influences and the opportunity for observation of them.

Parameters which determine the reaction of greenhouses on the specified influences on one side, and the microclimate in the greenhouse on the other, include temperature and air humidity, illumination, speed of air movement, dioxide carbon amounts, air temperature near plants, etc. [1-3].

Sources of disturbances are meteorological conditions on the territory of greenhouses, solar activity, work stability of the heat supply point. Given the random nature of meteorological conditions and solar activities on the territory of greenhouses, as well as oscillations of heat loss during heating, it is possible to assert the existence of currently undefined external influences. As a result, this causes currently undefined change of microclimate in greenhouses. At the same time, the characteristics of the

environment change, causing change in thermophysical properties of materials from which the greenhouse is made. The appearance such changes alters communication between influences and reactions of the greenhouse. The need occurs for allocation of minimum parameter sets for the greenhouse microclimate, the knowledge of which will ensure the ability to effectively control said microclimate.

2.2. Methods and systems of greenhouse microclimate formation

Microclimate in greenhouse structures depends on a whole complex of parameters - temperature and humidity of air in indoors buildings; external temperature and speed of air; contents of carbon dioxide in the area where plants are located.

Lighting over plants and microclimate parameters play a decisive role in creation of optimal growing conditions for vegetables, as well as stimulating the main processes of their life activities: photosynthesis, respiration, transpiration, root and outside life supply.

It is established that contents of carbon dioxide in the greenhouse succumbs to significant fluctuations. At high CO_2 concentration in the soil the majority of plant root systems suffer.

Decrease of oxygen adversely affects plants. In soil, especially with complex air exchange that takes place in greenhouses, insufficient oxygen amounts cause death of roots or at least deceleration of breath.

An important indicator of transpirational ability in plants - relative air humidity. In order for transpiration to not stop, humidity in the greenhouse is kept at about 70%.

Ventilation systems [1, 2] include mechanical system for opening and closing two or three upper and side transoms simultaneously. In greenhouses two types of programming devices are used that manage the ventilation system. One can be used to regulate the degree of opening or closing the transoms, and with the help of the other open them as much as possible when exceeding the given temperature and close completely at a decreased temperature. There are systems in which transoms are opened depending on temperature and relative humidity in the air from an impulse from a special hygrostat.

To provide optimal soil moisture, the drip irrigation system is used in greenhouses [8]. Feed supply is adjusted automatically in certain time intervals under each plant in its root system. Signals for turning the drive on / off are received from systems controlled by sensor signals monitoring temperature and humidity. To provide optimal air humidity in the majority of greenhouses a sprinkler system is used, which is controlled by remote control management.

Thermal modes of greenhouses are supported by heating and ventilation systems. It is defined by the power of heat sources, as well as constructive features of buildings. Precision in maintenance of given temperature — within ±1°C. In addition, the set temperature must align with the level of illumination that is related to physiological specialties of plants' life activities [6].

Controlled and regulated influence on soil temperature, internal air temperature of the greenhouse, temperature of plant covering and the temperature of the fence during vegetable cultivation is changed through the power of soil and air heaters.

Maintaining necessary humidity in air and soil is done through the help of

various irrigation systems (above-ground, underground, drip irrigation) [8].

The most important condition for receiving tall crops from greenhouse cultures is taking into account the relationships between modes and parameters, their coordination and support of necessary levels in greenhouses. Parameters exiting beyond the limits set by agrotechnical requirements during cultivation of vegetables in closed soil affects yield and marketable quality of products.

As indicated in works [9-12], greenhouse heating is carried out at the expense of solar radiation, biofuel, hot water or steam from boiler engines, industrial waste heat, electric heating installations. When heating the soil and air with hot water, quantitative temperature control is carried out. Research of transitional processes in greenhouses and structures of enclosed ground as an object of illumination regulation in the literature is not enough.

Electric heating of greenhouses significantly simplifies automatic control process of temperature and humidity of microclimate within greenhouses. Quality soil and air temperature control is carried out through heating elements, with the help of thermoregulating equipment - thermoregulators, thanks to which the heating system receives high degree dynamism and the ability to accurately maintain the temperature within the specified limits [11].

Heating soil in greenhouses is carried out with the help of (electrical shades, cables, mats, etc.). To provide optimal temperature for soil the capacity of 75-100 W/m^2 is enough [10].

It is fundamentally necessary to also use energy to provide sanitary and hygienic working conditions for workers, that includes energy costs for heating, lighting and ventilation etc. Side consumption of energy also includes energy to keep production capacities in working conditions.

The primary disadvantage of electric heating remains the cost of electricity. Price for every kWh of energy, as well as the economy of it, significantly affects the final cost, which means competitiveness grows in greenhouses products. Special value is given to management capacities heaters.

Change of heat supply from heating systems is carried out with regulation of temperature in the greenhouses. The greenhouse is the only energetically closed system, which consists of: heating subsystems, ventilation and heatsystems for enclosing structures.

For calculations of heating systems and ventilation in greenhouses it is important to fold adequate heat balance of the greenhouse, i.e to develop a mathematical model of technological process formation of an optimal microclimate in a real greenhouse.

Depending on the purpose and necessity of calculations in each specific case there are included the heat balance of all or few parts. In work [7] are given calculations for thermal losses in the greenhouse, which depend mainly on differences between external and internal temperatures and from methods and rules of temperature and humidity control modes.

Considered in the works are quality power management over the whole heating system, as in the management is related to change of heat carrier temperature.

During development of mathematical models of the greenhouse as an object of management, dynamic greenhouse air temperature dependence systems from the heat

intensity of the heating systems are installed. The greenhouse is represented as an object of control with two volumes: air volume and soil volume. Considering the increase of temperature relative to height in the greenhouse, air temperature in the ground layers should be taken from 0.9 value at a height of 0.5 meters [19].

Heating systems in greenhouses are closely related to problems with energy saving, which are given many attention due to the fact that greenhouse vegetable growing is energy intensive in rural areas of economy.

Methods of microclimate management in the majority of industrial greenhouses are not optimal and do not take into account cross connections between parameters that lead to untimely coolant submissions, overspending energy and, as a result, lack of supply harvest vegetables.

2.3. Managemen technologies of microclimate parameters in industrial greenhouses

To choose optimal growing conditions of vegetables the microclimate mode is monitored for days according to plant growth phases, taking into account the differences of cultivated crops and varieties. As an example, in fig. 1 is presented the graph of changes in temperature and air humidity in the greenhouse over a day. At night, the temperature *t1* is maintained unchanged, an hour before sunrise, the temperature in the greenhouse increases to the value *t2*, air dries out, and at sunrise, water does not condense on plants and fruits, as such begins the normal process of photosynthesis.

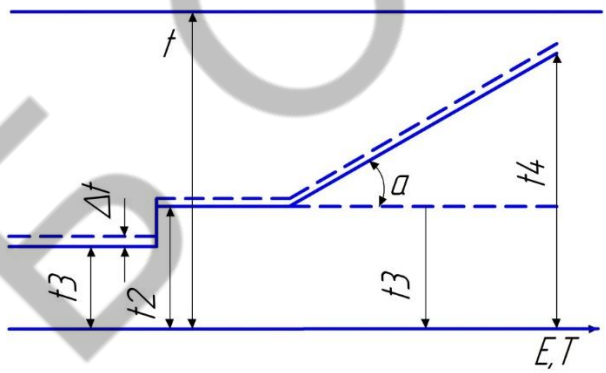

Figure 1 - Graph of dependencies between air temperature *t* in the greenhouse over a day taking into account illumination *and* the time of day *T*

During cloudy weather of day, the temperature *t3 is* maintained, equal to temperature *t2*. In sunny weather, starting with lighting of 2000 l k, the temperature is increased according to the value of illumination to temperature *t4*. After this ventilation transoms open, and excess heat leaves the greenhouse. Transition from daytime temperature until night is carried out after sunset. Angle of inclination *α* of line excess daytime temperatures in sunny days depends on the temperature on a cloudy day depending on the time of year.

Interconnection of microclimate parameters in the greenhouse and their changes over time, which are the basis of developed principles and program management of climate in greenhouses [19]. Changing the heat supply from systems heating and ventilation is carried out through control and regulation of temperature in the

greenhouse rooms.

Based on the results of theoretical studies [2 3] greenhouse as a control object of the temperature and humidity modes, can be considered a multidimensional object of control and be presented in the form of a scheme (Fig. 2).

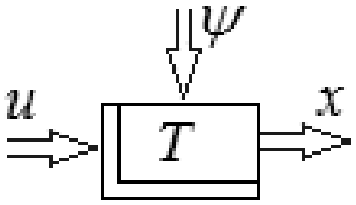

Figure 2 – Theorethical image of a greenhouse as an object managing its microclimate parameters

An extremely important criteria for management is economy of energy resources. It is known [7] that to achieve this goal there exist multiple options. The first is actively using lower contours of heating, because they give off the least heat to the outside environment. The second - upkeeping temperature near the growth point higher than near the roots of plants that allow active usage of upper heating contours. Another criteria of management is based on the fact that the lower contour should support the root zone's constant temperature, the so-called optimum, and only when other resources are exhausted executive systems should it deviate from it. Experience in implementation of automated control systems shows that at the stage of designing systems it is quite difficult to choose only one criteria of management. Therefore, the ability to quickly set criteria during operation should exist in the system, moreover the method of its task should display agronomic, economic and technical requirements that are required from the systems.

A modern management system should allow to set not only one of the above listed criteria or their combination, but also any another that occurs in the process of production, providing the agronomist-technologist with wide possibilities in choosing a method of maintaining the temperature and humidity mode in the greenhouse.

Microclimate management system in industrial greenhouses can manage:

- by three divided heating circuits - tent, above-ground, lateral;
- by two levels of heaters;
- by four drives of apartments.

Comparative analysis of existing microclimate parameter control systems in industrial greenhouses of the world's manufacturers allows to make a conclusion about the importance of optimization in systems of management. Which provides complex usage advantages of all the specified systems. The main parameters of greenhouse microclimate, which should be regulated, is temperature and humidity.

There are a few known levels of automation, with different completeness of performed actions and their complexity [7]. Systems of microclimate management in vegetable growing enclosed soil are described in many works [10-19]. Multifaceted analysis of this question is given in the works. Microclimate management system has a two-level structure. Upper level (operator post) is represented by a personal computer, and the lower one – by subsystems of management in greenhouses. Each of

the subsystems has a local remote with a sign-digital indicator that provides control of the measured parameters and setting regulation contours. Lower level operates autonomously, carrying out microclimate management and forming daily measurement archives.

Microclimate management systems use a microprocessor controller. The controller registers value parameters of internal and external environment in greenhouses, after which management of executive devices occurs - heating, ventilation, shading, feeding carbon dioxide, evaporative moisturizing and cooling air.

Functions of upper equal management systems are performed by the central station, which provides centralized observing of all greenhouse structure modes and automatically archives parameters and freelance situations, as well as allowing centralized introduction of microclimate support settings for controllers of lower levels. Functions of management optimization are aimed for receipt of the most effective technological modes [13].

Today, one of the most important parameters in microclimate is humidity, which is measured constantly. Indicated requirements in combination with requirements for energy-saving technologies require the installation of big quantity executive systems in a greenhouse. It's divided into several contours of the heating system, blinds, fans and so on.

Heat supply system relative to temperature schedules, when the temperature of the coolant is hard tied to the external temperature, leads to some places of Ukraine to overspend of fuel or lack heat in the greenhouse.

Thus, the automated microclimate control system has to collect information and make decisions. Based on all collected data, a modern management system must calculate the necessary number of energy and distribute it between all heat sources. When using computer technology it is possible to improve the process of microclimate software in greenhouses using a modern neural network. Management system of temperature and humidity modes of the greenhouse from a computer application consists of hardware and software provision. It gets information from many sensors:

- external - speed and direction of wind, air temperature, lighting, humidity, precipitation intensity, position of transoms and the screen;
- located within greenhouses - temperatures and humidity in different departments, CO_2 concentration, temperature of plants, sensors that measure the intensity of natural and artificial light radiation in the most spectral region important for photosynthesis between 400 and 700 n.m.

System with supported software is performed through a personal computer together with the controller for communication with sensors, allowing to adjust the temperature in the room of the greenhouse and its microclimate as a whole, decides the following tasks: 1) displays on memory cards and records in the computer for a long time (several months, years) the temperature and humidity of air in the greenhouse and outside, wind speed, temperature and pressure of forwards and backwards water streams in the heating circuits, atmospheric pressure, lighting, etc.; 2) supports required temperature and air humidity within the necessary limits of the greenhouse structures; 3) uses steam heating or others systems heating for regulation of temperature; 4) controls transom drives; 5) informs the operator when the controlled parameters exit

acceptable boundaries; 6) records emergency situations in files.

Features of such systems are, on the one hand, simplicity and, accordingly, low costs, and on the other hand, insufficient cost quality management, impossibility of operational accounting of all controlled parameters and exact matching of many technological systems, high degree responsibility on service personnel and dependence from their qualifications and experience.

Increase in efficiency related to the necessity of intellectualization of the choice process of the dispatcher's decision in complex systems. The first step on the way to increasing effectiveness of local automatic control systems with separate technological parameters (temperature of the coolant in the heating circuits and water in the irrigation system, pressure drop in the heating network, liquid levels in containers, solution concentration etc.) on the set levels [14, 15]. Usually separate parameters are located under influence of small quantity disturbances and interferences and therefore are relatively easy and reliably are carried out by their automation management. In general, the whole set of individual technological parameters forms microclimate in the greenhouse, determining the conditions for growing a harvest. As a rule, individual self-propelled guns for different technological processes are installed and function regardless of each other, representing autonomous systems. Creation of such self-propelled guns allows to raise the quality of management for separate technological parameters, releasing simultaneous dispatchers from enough time-consuming and monotonous work that indirectly helps increase the quality of support for the microclimate in as a whole.

On the other hand, low quality coordination between effects on individual parameters of a microclimate marginally limits possible increase in efficiency. The next step on the way to increasing efficiency became the creation of automated microclimate control systems (ACS) in greenhouses, which provides support parameters for microclimates (air temperature, soil, humidity of air and soil, lighting level, parameter systems for nutrition of plants) on the set levels [2 3]. Such systems affect the entire complex of technological processes in the greenhouse, including systems that separate water heating, calorific and/ or gas heating, transom or recirculation ventilation, blinds, electric secondary lighting, volatile cooling and permitting air (mist system) etc. In such systems, the goal of control is not a separate executive mechanism, and parameters of a microclimate, the main of which are temperature and humidity of air.

From the conducted comparative analysis capabilities of microclimate control systems in industrial facility greenhouses of the world manufacturers and information laid out above, it can be seen that all considered systems are not taken into account the irregularity of energy carriers consumption that leads to them overspending.

In the simplest case energy efficiency from use of management systems is expressed through savings on energy costs under the condition of compliance with the regulatory requirements of the microclimate.

One of the promising directions for decrease of expenses on growing products, assuming compliance to agrotechnical requirements is electrical heating.

As can be seen from the analysis of the state of research in the field automation processes, microclimate management in the greenhouse to achieve the goal of research

is possible during implementation of methodology systems of automatic control of the temperature and humidity modes. By choice such methodology affects many factors [16]: the nature of the change signals in control paths, disturbances; dynamics greenhouses as an object of management; type and properties regulatory bodies; source type energy, etc.

Considering complexity of direct measurement between value norms of effective energy consumption and communication of its importance and agrotechnical conditions growing certain crops in the greenhouse, it becomes clear that for the increase of energy efficiency in the process of growing vegetables at the expense of automation process management it is best to develop an analytical system of self-adjustment with a neural network calculator.

When practical implementation of such systems occurs the need for technical means capable of performing measurements of the indicator of the goal of management in the conditions of uncertainty.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The purpose of this section is development and research systems control of the temperature and humidity regime in the greenhouse on the basis of experimental data and created mathematical models that describe the temperature and humidity regime in the greenhouse. Expediency application of artificial neural networks for construction of intellectual systems of temperature and humidity regime management in the greenhouse confirmed non-linearity and complexity intrasystemic connections.

Existing systems for ensuring optimal parameters of the microclimate in greenhouses have a number of shortcomings - the temperature on the surface of plants is not taken into account, the influence of solar radiation is not comprehensively evaluated, the change in temperature and speed of movement of external air flows, the material and construction of the fence, as well as other factors that have a random nature.

In order to study the influence of these factors on the yield of vegetables in the greenhouse and the possibility of controlling the parameters of the microclimate and lighting of the plants, we developed and created a layout of the greenhouse, which is equipped with the latest electronic equipment, modern executive mechanisms and an intelligent system that provides automatic control of the microclimate of the greenhouse and the lighting of plants at compliance with the energy saving mode (Fig.3).

Control of soil and air temperature is carried out by fast-acting temperature transmitters placed, respectively, in the soil at the level of plant roots and in the air.

The executive mechanism for regulating the soil temperature in the greenhouse layout is resistive heating elements powered by the electrical network. Heaters, electric heating carpets, etc. can be heating elements. There is also an executive mechanism that quantitatively controls the flow of liquid coolant in a real greenhouse. Thermal mirrors are used to reduce heat losses directed in the direction opposite to the plants.

Figure 3 – External appearance of the greenhouse layout

Air heating in the greenhouse is carried out with the help of a ventilation system with a recuperative air-to-air heat exchange device, which simultaneously takes into account the level of carbon dioxide according to the given air exchange.

To heat and ensure the optimal composition of the air in the room of a real greenhouse, it is suggested to use a supply and exhaust system of the VUT type with heat recovery. The power of the installation is determined by the volume of the greenhouse. It is possible to control the air temperature in the greenhouse using infrared heaters.

Humidity control of the greenhouse atmosphere is carried out using a humidity sensor. Air humidification is optimized using a fog generator.

To equalize the heat and moisture fields in the volume of the greenhouse model, a fan, shown in Fig. 4, is designed.

Figure 4 – Fan equalizing heat and moisture fields

Measurement of natural external illumination is carried out by an illumination sensor. The sensor is placed on the external upper transparent surface of the enclosure of the greenhouse layout.

When the external illumination is reduced to a critical level, the automatic switching on of the LED lamp, made of a block of LEDs emitting in different parts of the visible radiation spectrum, is provided (Fig. 5).

Figure 5 – Appearance of LED lamps

The spectral composition of the lamp's radiation is adjusted to a certain type of plant. The individual need for the spectral composition of the radiation of a certain type of plant is satisfied by the appropriate setting of the lighting system.

The content of carbon dioxide is determined using a suitable sensor. The unified electric signals of the sensors, which inform about the state of the microclimate parameters of the greenhouse, are directed to the original information processing device, created on the basis of a microcontroller Arduino (Fig. 6). An information processing device connected to a personal computer forming an intelligent system for controlling the temperature and humidity regime of the microclimate of the greenhouse and lighting the plants in it.

Figure 6 – Appearance of the information processing unit

An original program has been developed for processing parameters of technological information and control of executive mechanisms.

Figure 7 – Appearance of the information processing device

The developed and implemented intelligent automatic control system allows local and remote monitoring, control and management of microclimate parameters and greenhouse lighting parameters using the GPRS system. The system can be adapted for both industrial and private greenhouses.

IV. RESULTS

An operational layout of the greenhouse was developed for the study of the developed original system of automatic local and remote control of microclimate parameters based on the domestic K-1 microcontroller with its subsequent adaptation to greenhouse farms.

The designed and manufactured operating model of the greenhouse has an automatic control system based on the K-1 multi-channel programmable controller, which makes it possible to quickly and automatically control the microclimate of the greenhouse, providing optimal conditions for growing vegetables.

In fig. 8 main elements of the greenhouse layout are schematically presented: 1 – the body of the layout, made of transparent polystyrene; 2 – a metal tray with soil for growing vegetables; 3 – resistive thermal elements of soil heating; 4 – reflective thermal mirrors; 5 – resistive air heater with a nozzle that has a fan; 6 and 7 – thermoresistive measuring transducers of the TOM-1 type for measuring soil and air temperature, respectively; 8 – measuring transducer of air humidity type DV-2. 9 – fog generator and 10 – fan are used to ensure uniform air humidity in the volume of the greenhouse.

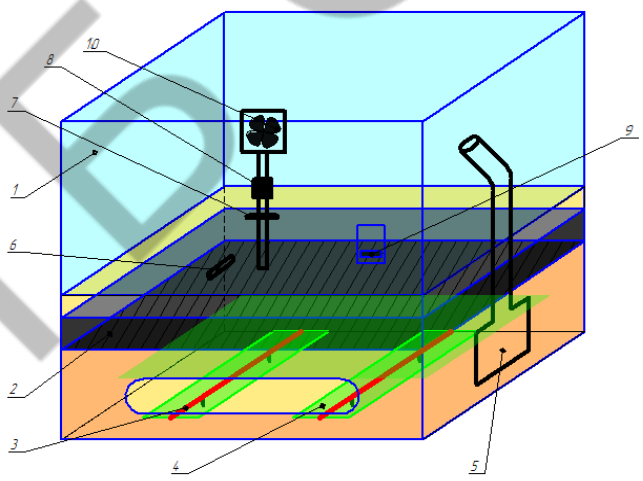

Figure - 8 - External appearance of the greenhouse layout

A personal computer connected via an interface to the system of automatic control of the microclimate parameters of the greenhouse layout allows for local and remote monitoring, control and management of the microclimate parameters of the greenhouse using the GPRS system.

Designed and manufactured a laboratory-demonstration working model of a greenhouse, which has an automatic control system based on a multi-channel programmable microcontroller K-1 combined with a personal computer gives the

opportunity to familiarize with the principles of automatic local and remote measurement, control, management and monitoring of greenhouse microclimate parameters using the GPRS system. Re-equipment of greenhouse farms, transferring them to an industrial basis with the use of modern automatic systems for controlling microclimate parameters makes it possible to solve the problem of sustainable supply of the country with high-quality vegetables in the required quantity.

K1 is a multi-channel panel programmable logic controller designed to control technological processes in greenhouses.

Function is implemented as a programming language in the K1 controller Block Diagram (FBD). K1 contains a library of functional blocks, which is divided into several conditional groups: input-output blocks, mathematical, logical, process control 1, process control 2, miscellaneous.

The process of programming the controller is the construction of a scheme of the technological process with the help of virtual functional blocks located in its library.

Programming of the controller from a computer is carried out in the P-CAD environment using a library of functional blocks. The proposed system of automatic control and management of greenhouse microclimate parameters based on the K-1 controller is designed for:

- microclimate control in the middle greenhouses,
- external tracking weather conditions,
- analysis of received data

developed automated control system based on the K-1 controller can be implemented in any greenhouse.

V. CONCLUSIONS

When performing the research, the following results were obtained:

1. It has been proven that the reasons for the decrease in the efficiency of growing vegetables in enclosed soil are related to the shortcomings of the existing approaches to the creation of temperature-humidity control systems.
2. The analysis of models of the dynamics of the arch type greenhouse, obtained analytically and experimentally, showed its controllability and observation, if soil and air heating are used to control the microclimate. The expediency of air temperature changes with constant soil heating has been established.
3. It was established that the input data required for the operation of the sampling unit of the temperature-humidity control system in the greenhouse should include: external air humidity, heat index, internal air humidity, air temperature near the plants.
4. As a result of the synthesis of an intelligent adaptive automatic control system, the following software modules were developed: a control system, a database, a software block for forming a sample of technological data, which made it possible to create a convenient interface for the operation of operational technologies.

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DEVELOPMENT OF A PLANT FOR THE MANUFACTURE OF WEAR-RESISTANT PARTS OF MINING EQUIPMENT

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Abstract. *Increasing the service life of rural-urban parts. machines is one of the main tasks facing the engineers of the agro-industrial complex. One of the ways to solve this problem is to develop new alloys and improve existing ones. There are many methods of improving the quality of cast metal. Functional capabilities of these methods are multifaceted and multipurpose. But there is no single universal method capable of affecting metal equally effectively. One of these new methods is the treatment of crystallizing liquid metal with an electric pulse discharge. Previous studies have shown that such processing has a sufficiently high efficiency. At the same time, it remains innovative and currently underexplored.*

Therefore, to solve this problem, it is advisable to develop electrical equipment for the implementation of the technology of non-baking processing of metals and alloys.

Keywords: *electrode system, VEO, pulse current generator, pulse, macrostructure of ingots, crystallization process.*

I. INTRODUCTION

Increasing the service life of rural-urban parts. machines is one of the main tasks facing the engineers of the agro-industrial complex. One of the ways to solve this problem is to develop new alloys and improve existing ones. There are many methods of improving the quality of cast metal. Functional capabilities of these methods are multifaceted and multipurpose. But there is no single universal method capable of affecting metal equally effectively. The current state of this issue is developing both in the direction of improving each traditional method and in the direction of finding alternative technological methods of processing. One of these new methods is the treatment of crystallizing liquid metal with electropulse discharge. Previous studies have shown that such treatment has a sufficiently high efficiency.

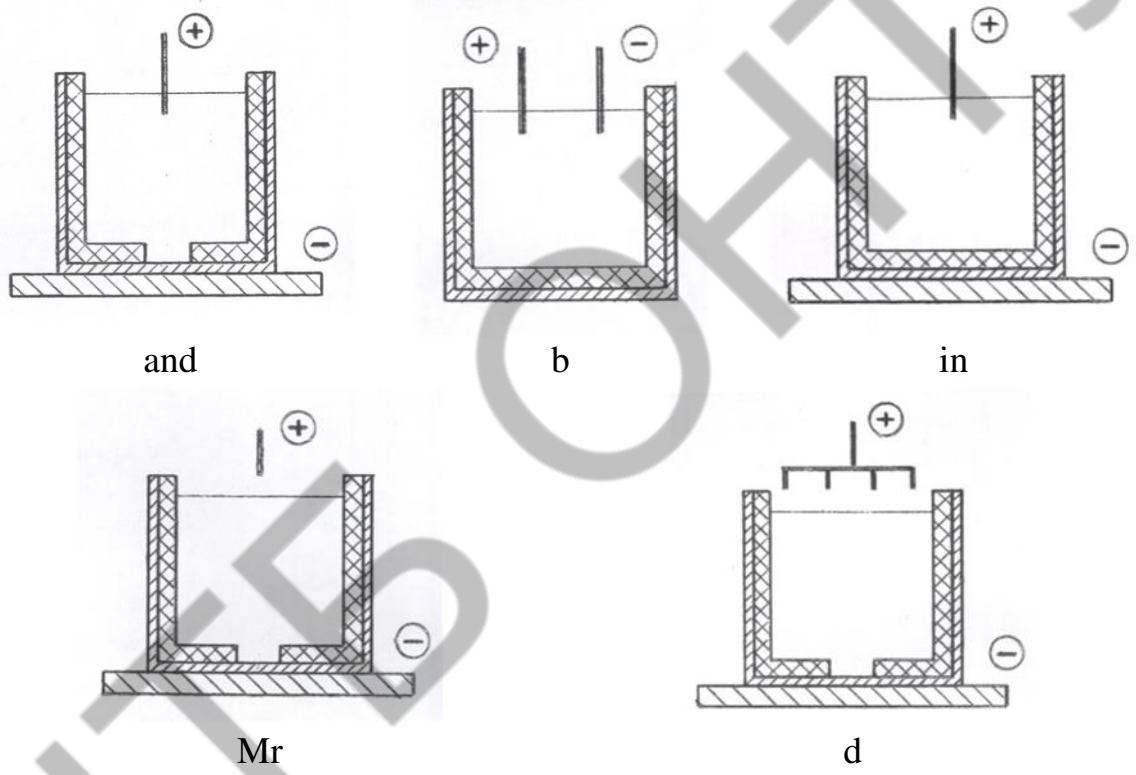
The purpose of this study is to design an electric discharge unit for out-of-furnace metal processing for the production of wear-resistant parts of agricultural machinery.

In order to achieve the given task, the current state of non-furnace current processing of metals and alloys in the melt and at the crystallization stage was analyzed, simulations of the electric discharge processes of processing metals and alloys with high-voltage pulsed current at the crystallization stage were carried out, electrical engineering equipment was developed for the implementation of the technology of non-furnace processing of metals and alloys, on stages of crystallization, and an experimental study of the influence of the parameters of the electric discharge unit on the crystallization process, structure and properties of aluminum alloys was performed.

II. LITERATURE ANALYSIS

The duration of experimental studies of the processes being studied does not allow them to be analyzed in all the variety of varied parameters. A numerical experiment is more effective in this regard. The data obtained in this way allow us to approach the understanding of the mechanisms of electropulse processing of liquid melt, which are directly related to the electromagnetic phenomena that occur in the melt when an electric potential is applied and the passage of a discharge current [1]. Let's consider different options of electrode systems (Fig. 1), which are most likely to be used in practice:

1) point - plane;
2) point - point;
3) the tip - the walls of the ladle [2].



and b in

Mr d

Fig. 1 – Electrode systems for experimental research: a, b, c – for processing the crystallizing melt; a, d, d – for liquid metal processing

Modeling of electromagnetic processes in liquid metal with a macroscopic approach is performed by solving Maxwell's equations with certain boundary conditions. It is appropriate to use the system of Maxwell's equations, written in differential form, because it allows us to use numerical finite-difference methods for solving [3].

In the general case, for quasi-stationary fields, this system of equations is written as follows:

$$\nabla \times H = J = \sigma(E + v \times B) + J^e, \quad (1)$$

$$\nabla \times E = -\frac{\partial B}{\partial t}, \quad (2)$$

$$\nabla \times B = 0, \quad (3)$$

$$\nabla \times D = 0, \quad (4)$$

$$\nabla \times J = 0, \quad (5)$$

where ∇– the Nabla operator; H – magnetic field strength in the melt, A/m; J– current density, A/m2; σ – specific electrical conductivity, S/m; E– electric field strength, A/m; v – speed of the object, m/s;v=0 B– magnetic field induction in the melt, Tl; – density of induced (extraneous) currents, A/m2; D – electric induction, Kl/m.J^e

We invert the conductivity tensor. Then equation (1) can be written in the form:

$$E = \sigma^{-1}(\nabla \times H - J^e) + v \times B, \quad (6)$$

Let's replace E according to Faraday's law, substituting the most general equation for magnetic induction:

$$B = \mu_0 \mu_r H + B_r, \quad (7)$$

where B_r – induction of external magnetic field, Tl; μ_0 is the magnetic constant, $4\pi \cdot 10^{-7}$ Hn/m; μ_r – relative magnetic permeability, $\mu_r = 1$.

We obtain the general equation for a quasi-stationary electromagnetic field:

$$\frac{\partial}{\partial t}(\mu_0 \mu_r H + B_r) + \nabla \times (\sigma^{-1}(\nabla \times H - J^e) - v \times (\mu_0 \mu_r H + B_r)) = 0, \quad (8)$$

In order to take into account the problems arising in regions with zero conductivity, μ_r and B_r let's represent it as a function of the magnetic field strength, taking the partial derivatives with respect to time. We will get:

$$(\mu_0 H \frac{\partial \mu_r}{\partial H} + \mu_0 \mu_r + \frac{\partial B_r}{\partial H}) \frac{\partial H}{\partial t} + \nabla \times (\sigma^{-1}(\nabla \times H - J^e) - v \times (\mu_0 \mu_r H + B_r)) = 0, \quad (9)$$

To solve this equation, we will use the Femlab software environment (system), in particular, its module Quasi-staticfields/MeridionalCurrents/Transientanalys, which allows analyzing processes changing in time by solving differential equations using the finite difference method.

Since the container with aluminum melt has a cylindrical shape, it is convenient to look for the solution in the cylindrical coordinate system (z, r, φ). Dimensions of the conductor (melt) - radius R0 = 45·10-^{3}m; heightHk = 90·10-^{3}m.

We will carry out the calculations using the following parameters of the discharge circuit (which were used for processing) as an example – U0= 31 kV; L= 1.787 μH; C= 1 μF.

2.1. Electrode system "Point - plane"

The "Point - plane" electrode system corresponds to the case when the melt is in a container with lined (non-conductive) walls, and an unlined steel bottom acts as a counter electrode [4]. The geometric model of the conductor is presented in (Fig. 2).

Let us assume that the Z axis coincides with the bucket axis, the angle φ = 0. The magnetic field in the object depends on the angle φ, and the current and electric field depend on r and Z.

Let's assume that the current from the positive electrode E flows into region 5 on the negative electrode.

Let's write down the equation of the magnetic field in a ladle with melt with respect to the variable H_φ. Since there is no external magnetic field source, then $B_r = 0$.

$$\mu_0\mu_r \frac{\partial H_\varphi}{\partial t} + \nabla \times (\sigma^{-1}(\nabla \times H_\varphi - J^e) - v \times (\mu_0\mu_r H_\varphi) = 0, \quad (10)$$

where H_φ – intensity of the magnetic field in the object, A/m.

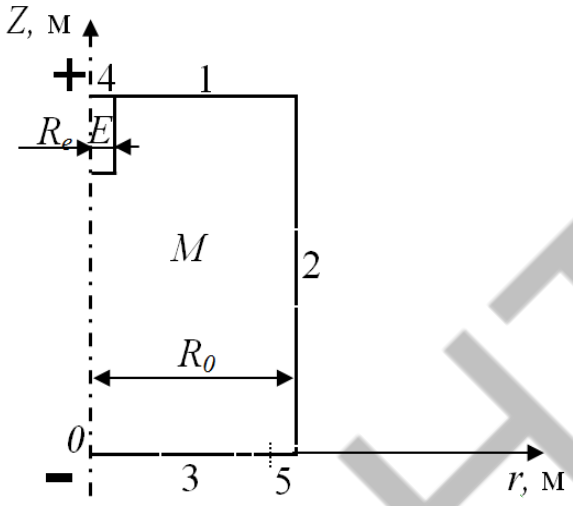


Fig. 2 – Geometry of the conductor for the electrode system "Point - plane"

If equation (10) is solved for the melt, then σ for liquid aluminum is substituted into it. Accordingly, if the electromagnetic field is described inside the electrode, the value σ characterizing solid steel is substituted into equation (10).

Assume that the initial speed of the melt and the density of extraneous currents$v$=0 $J^e = 0$. Suppose that on the axis Z $H_\varphi = 0$ Let's set the initial conditions: $H_\varphi\big|_{t=0} = 0$ and $I\big|_{t=0} = 0$.

Boundary conditions:

For area 1: $$H_\varphi = \frac{I(t)}{2 \cdot \pi \cdot r}, \quad (11)$$

For area 2: $$H_\varphi = \frac{I(t)}{2 \cdot \pi \cdot R_0}, \quad (12)$$

For area 3: $$H_\varphi = 0, \quad (13)$$

For area 4: $$H_\varphi = \frac{I(t) \cdot r}{2 \cdot \pi \cdot R_e^{\,2}}, \quad (14)$$

For area 5: $$H_\varphi = \frac{I(t) \cdot (r - R_0 + \Delta_{скін})}{2 \cdot \pi \cdot R_0 \cdot \Delta_{скін}}, . \quad (15)$$

The dependence I(t) can be specified analytically, or, as in our case, numerically, by digitizing the experimentally obtained amplitude-time dependence of the discharge current.

The current lines in this case will be distributed as shown in (Fig. 3), and (Fig. 4) shows the distribution of the amplitude of the magnetic field in different sections of the ladle at the maximum amplitude of the discharge current.

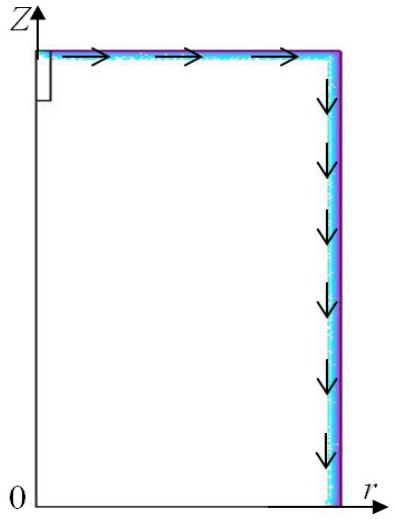


Fig. 3 – Distribution of current lines in the melt

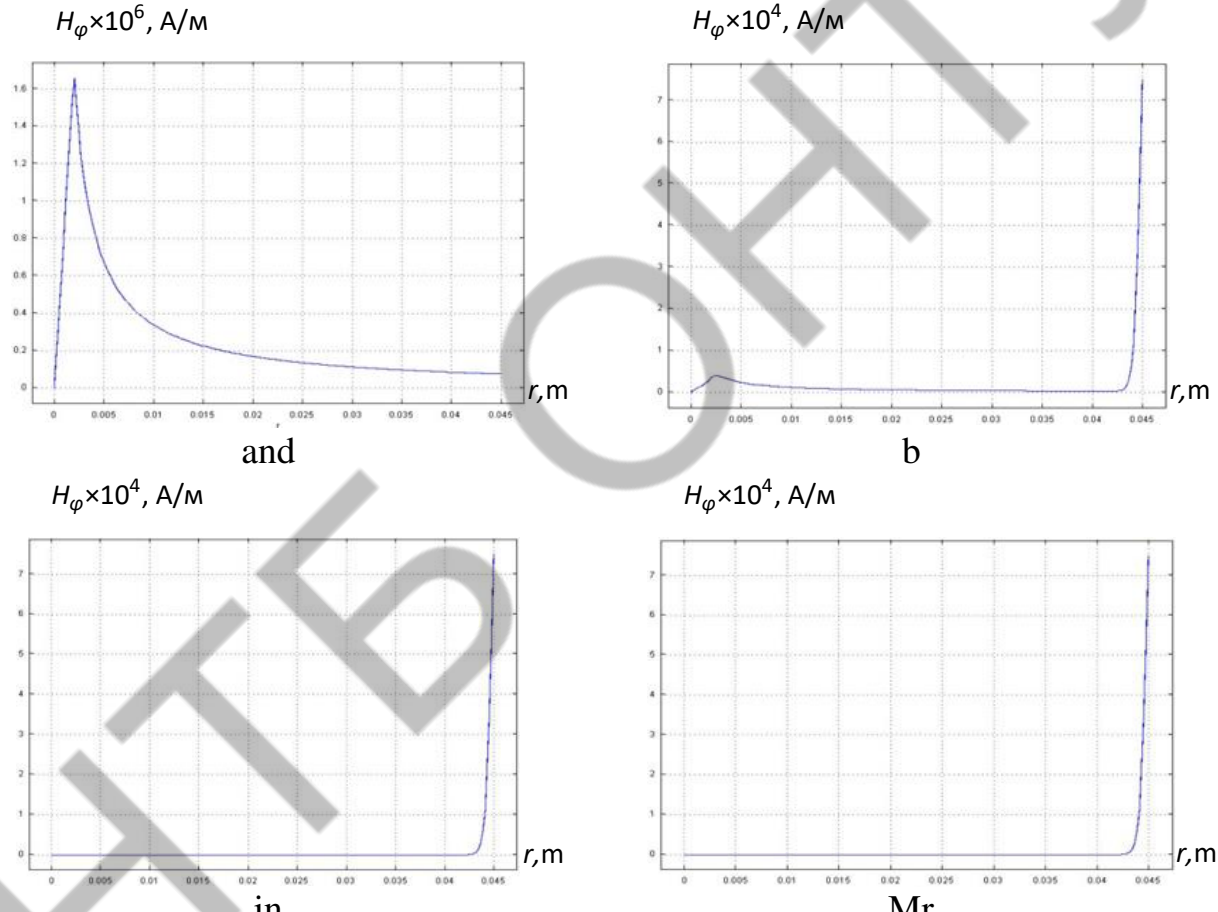


Fig. 4-Distribution of the magnetic field in different sections of the conductor at the maximum amplitude of the discharge current
a – melt mirror; b – Нк = 88·10-3 m; in – Hk = 45·10-^{3}m; d - the bottom of the bucket

We use the equation to find $P_{ем}$:

$$P_{ем} = \frac{\mu_r \mu_0 H^2}{2}, \quad (16)$$

where $P_{ем}$ – magnetic pressure, Pa.

We will obtain distributions of the magnetic pressure amplitude(Fig. 5).

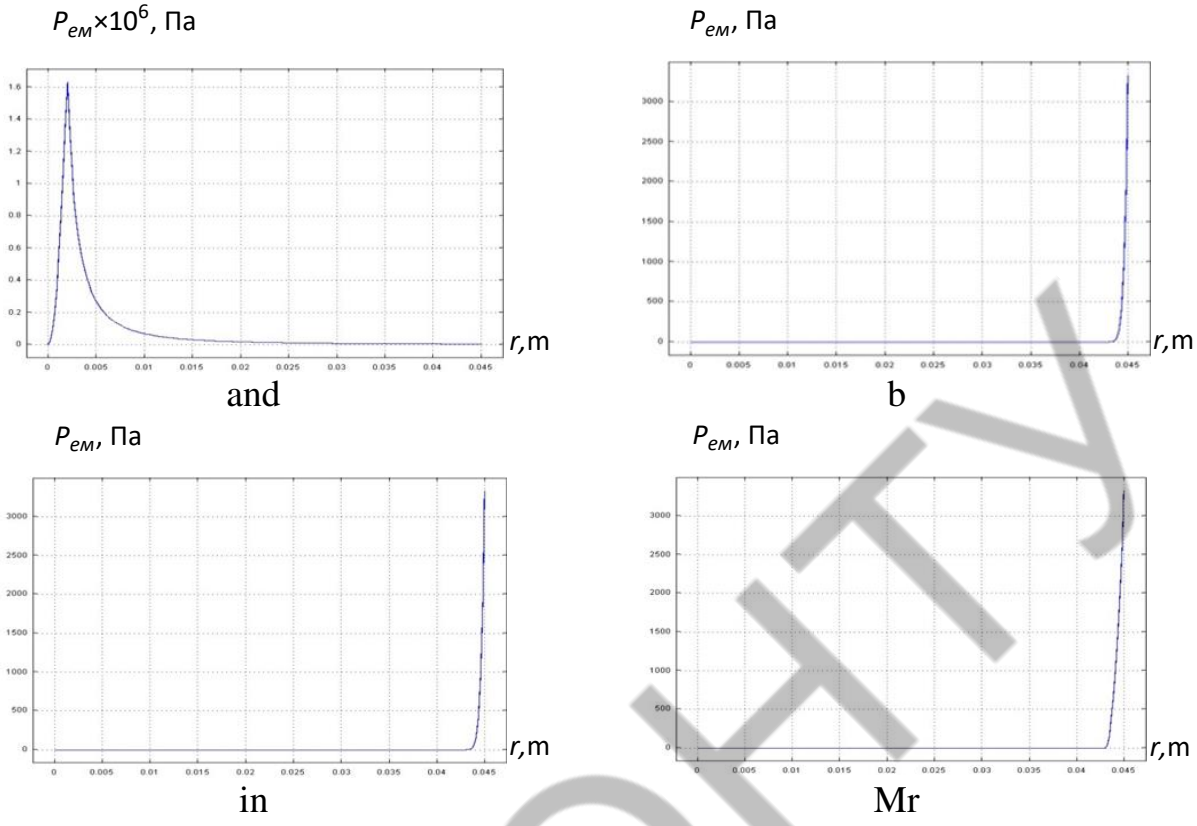


Fig. 5 – Distribution of magnetic pressure in different sections of the ladle at the maximum amplitude of the discharge current

2.2. Electrode system "Point - point"

This case describes a cylindrical ladle with a melt, through the mirror of which an electrode-current conductor is introduced [5]. The bucket itself is completely lined, but in the center of this part there is a round counter electrode, the diameter of which is equal to the diameter of the electrode-current conductor (Fig. 6).

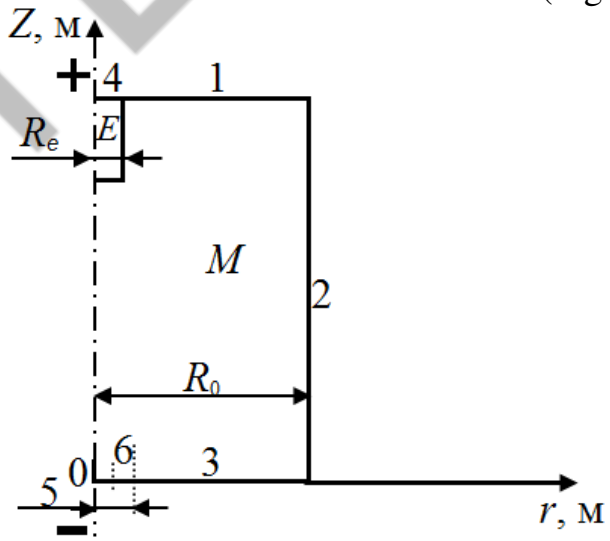


Fig. 6 – Geometry of the conductor for the electrode system "Point - point"

M– liquid cylindrical conductor (aluminum melt) with radius R0; *IS*– electrode with radius Re; 1 – melt mirror; 2 – side wall; 3 – ladle bottom; 4 – cross section of the electrode; 5 – counter electrode; 6 – skin layer thickness Δskin

The same module and equation are used as for the tip-plane electrode system. On the Z axis $H_\varphi = 0$. Initial conditions: $H_\varphi\big|_{t=0} = 0$ and $I\big|_{t=0} = 0$.

Boundary conditions:

For area 1: $$H_\varphi = \frac{I(t)}{2 \cdot \pi \cdot r}, \quad (17)$$

For area 2: $$H_\varphi = \frac{I(t)}{2 \cdot \pi \cdot R_0}, \quad (18)$$

For area 3: $$H_\varphi = \frac{I(t)}{2 \cdot \pi \cdot r}, \quad (19)$$

For area 4: $$H_\varphi = \frac{I(t) \cdot r}{2 \cdot \pi \cdot R_e^{\,2}}, \quad (20)$$

For area 5: $$H_\varphi = 0, \quad (21)$$

For area 6: $$H_\varphi = \frac{I(t) \cdot (r - R_0 + \Delta_{\text{скін}})}{2 \cdot \pi \cdot R_0 \cdot \Delta_{\text{скін}}}, \quad (22)$$

Current lines in this case will be distributed as shown in (Fig. 7).

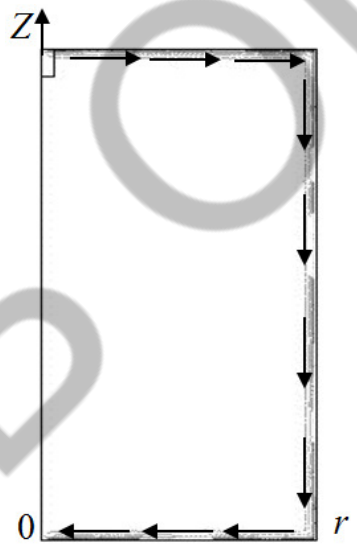


Fig. 7 - Distribution of current lines in the melt

The distribution of the magnetic field amplitude in different sections of the ladle at the maximum amplitude of the discharge current is shown in (Fig. 8), the distribution of the magnetic pressure in different sections of the ladle at the maximum amplitude of the discharge current is shown in (Fig. 9).

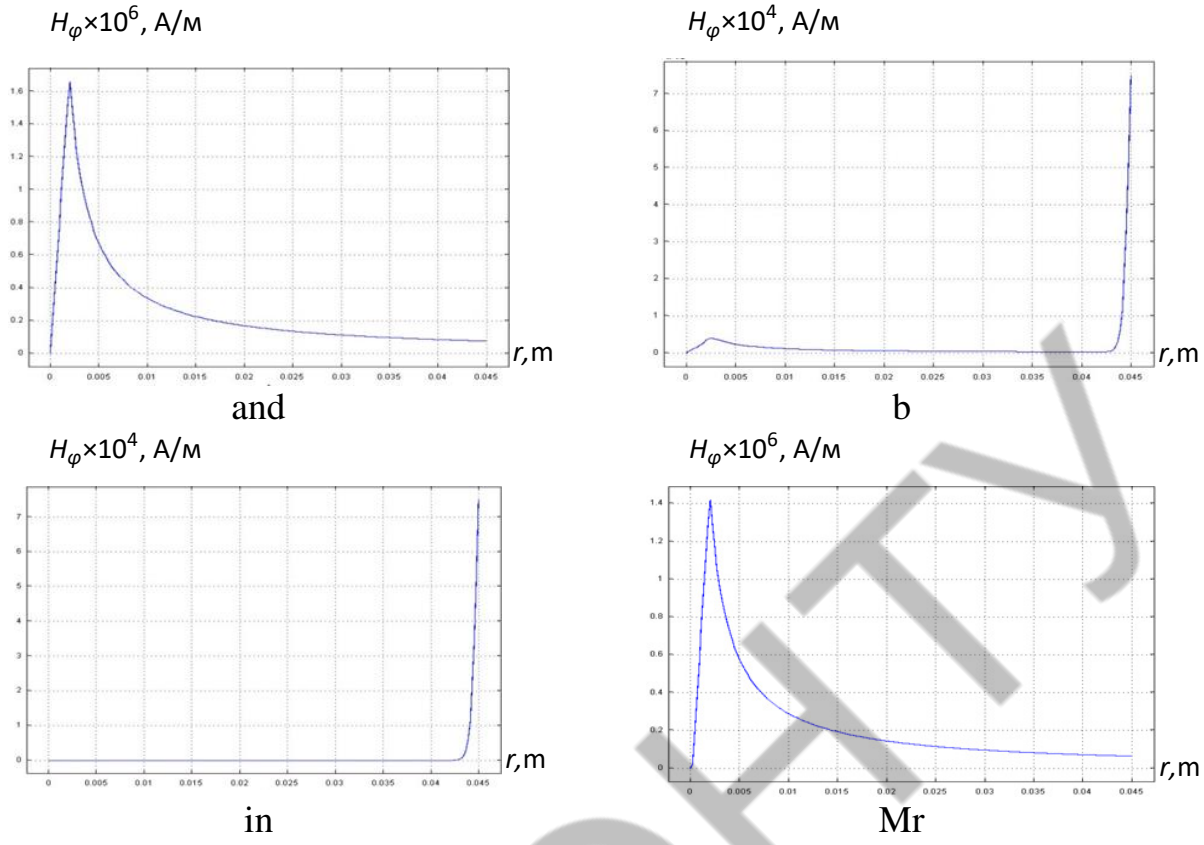


Fig. 8 – Distribution of the magnetic field in different sections of the ladle at the maximum amplitude of the discharge current
a – melt mirror; b – Hk = 88·10-3 m; c – Hk = 45·10-3 m; d - the bottom of the bucket

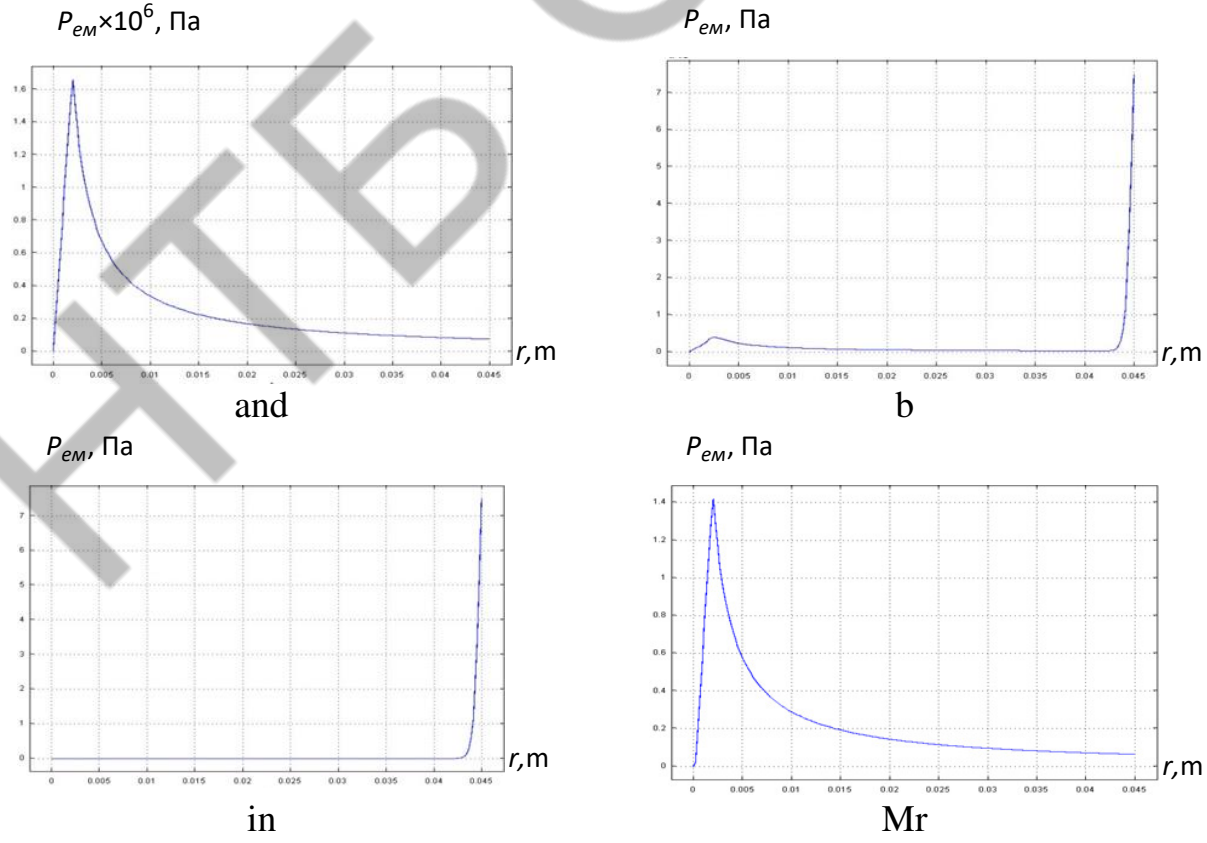


Fig. 9 – Distribution of magnetic pressure in different sections of the ladle at the maximum amplitude of the discharge current

2.3. Electrode system "Point - ladle walls"

The "Tip - walls of the ladle" electrode system consists of a current-carrying electrode immersed in the melt, a ladle with aluminum melt, in which the bottom is lined [6].

Estimates show that at a temperature of more than 650ºC, the values of electrical resistance (conductivity) of the material of the ladle walls and the melt are practically the same, so limit 2 is transparent to electromagnetic fields, and we do not take it into account.

The same module and equation as before are used. On the Z axis $H_\varphi = 0$. Initial conditions: $H_\varphi\big|_{t=0} = 0$ and $I\big|_{t=0} = 0$.

Boundary conditions:

For area 1: $$H_\varphi = \frac{I(t)}{2 \cdot \pi \cdot r}, \quad (23)$$

For area 3: $$n \times E = 0, \quad (24)$$

For area 4: $$H_\varphi = \frac{I(t) \cdot r}{2 \cdot \pi \cdot R_e^{\,2}}, \quad (25)$$

For area 5: $$H_\varphi = \frac{I(t)}{2 \cdot \pi \cdot (R_0 + Ш)}, \quad (26)$$

For area 6: $$H_\varphi = \frac{I(t) \cdot (r - (R_0 + Ш) + \Delta_{скін})}{2 \cdot \pi \cdot (R_0 + Ш) \cdot \Delta_{скін}}, \quad (27)$$

Expression (23) takes into account the so-called "magnetic isolation", i.e. at boundary 3 the normal component of the magnetic field is zero.

The following figures show how the electric current and magnetic field are pushed to the surface of the conductor (melt). This leads to the fact that the magnetic pressure in the bucket is distributed non-potentially (significantly unevenly). A significant concentration of the electromagnetic field and pressure in the near-electrode zones has also been established, which can be the cause of the excitation of eddy currents, the nature of which movement will be determined by the geometry of the electrode system and the nature of the deviation of electric current lines from a straight path (by the degree of scanning) (Fig. 10).

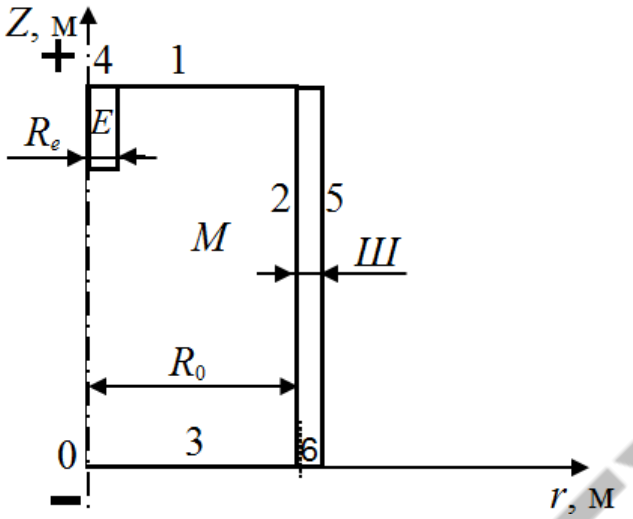


Fig. 10 - Geometry of the ladle with melt for the electrode system "Point - ladle walls" M – liquid cylindrical conductor (aluminum melt) with radius R0; E – electrode with a radius of Re; III – width of the wall of the ladle0.005 m;1 – melt mirror; 2 – side wall; 3 – bottom ladle; 4 – cross-section of the electrode; 5 – counter electrode; 6 – the thickness of the skin layer Δskin

In this case, the current will flow along the melt mirror and unlined steel walls, and the current lines (Fig. 11) in this case will be distributed. Since the main part of the current flows in the area of the melt mirror, we will limit ourselves to the distribution of the magnetic field and pressure only in this area (Fig. 12, see the appendix).

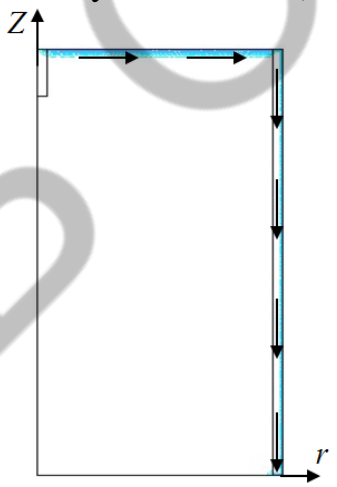


Fig. 11 – Distribution of current lines in the melt

The results of the calculations also showed that in the case of the "point - plane" and "point - point" electrode systems, at the maximum amplitude of the discharge current Imax = 22 kA, the pressure in the wall region of the melt does not exceed several kPa, which cannot significantly affect the state of the melt. In the case of the "Tip - ladle wall" electrode system, the electromagnetic field penetrates into the open steel wall of the ladle, there is a skin layer, and the magnetic pressure on the side surface of the melt is zero [7]. Meanwhile, the experimental application of such an electrode system made it possible to obtain positive changes in the structure and properties of the metal. This discrepancy can be explained by the fact that the calculations assumed

conductivity for pure aluminum. For high-temperature aluminum melts (alloys), such reference data are not available, but obviously that the conductivity for alloys will be lower, and the ratio of the conductivity of the melt and the steel wall will change as it cools. Thus, the real distribution of the current when using the electrode system "Tip - ladle wall" at different moments of time could differ from that shown in (Fig. 11), which will definitely need to be taken into account when modeling physical processes in the solidifying (crystallizing) melt.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

Relevance of work. Increasing the service life of rural-urban parts. machines is one of the main tasks facing the engineers of the agro-industrial complex. One of the ways to solve this problem is to develop new alloys and improve existing ones. There are many methods of improving the quality of cast metal. Functional capabilities of these methods are multifaceted and multipurpose. But there is no single universal method capable of affecting metal equally effectively. One of these new methods is the treatment of crystallizing liquid metal with an electric pulse discharge. Previous studies have shown that such processing has a sufficiently high efficiency. At the same time, it remains innovative and currently underexplored.

Therefore, to solve this problem, it is advisable to develop electrical equipment for the implementation of the technology of non-baking processing of metals and alloys.

The purpose of the work and research tasks: development of an electric discharge unit for non-furnace metal processing for the production of wear-resistant parts of agricultural machinery.

To achieve the specified goal, the following tasks must be solved in the work:

– conduct an analysis of existing electrode systems for high-voltage electric pulse treatment

– to carry out modeling of electric discharge processes of processing metals and alloys with high-voltage pulsed current at the crystallization stage.

– perform an experimental study of the influence of the parameters of the electric discharge installation on the crystallization process, structure and properties of aluminum alloys.

Object of study -processes that occur during electropulse processing of metals and design features of electrode systems for processing melts.

Subject of study–electric discharge processes that contribute to changing the structure of metals.

Research methods. Numerical and graphic methods are used in the work,methodsmathematical analysis, mathematical modeling and experimental research.

IV. RESULTS

The energy source for high-voltage electric pulse processing of the melt is the Pulse Current Generator (GIS), which is a battery of parallel-charged capacitors, the

number, voltage and capacity of which determine its energy. Energy in the battery accumulates over a relatively long time interval and is released in a shorter time interval in the melt [8].

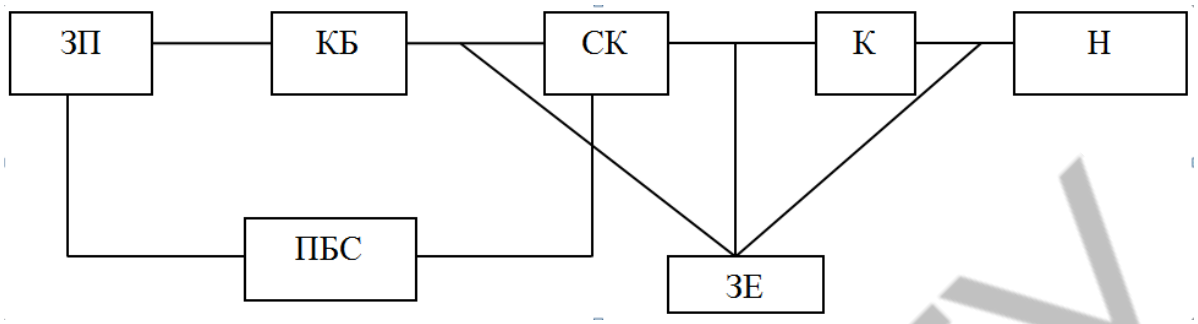


Fig. 13 – Structural diagram of GIS: ZP – charger; KB – capacitor battery; SC – switching system; K – collector; PBS - blocking and synchronization device; H – load; ZE - connecting elements

Calculations of the main GIS parameters were carried out according to the following formulas.

Energy stored in the capacitor bank W0:

$$W_0 = \frac{C \cdot U_0^2}{2}, \tag{28}$$

where C –capacitor battery capacity, F; U_0 –voltage to which the capacitors are charged, V.

Average power at the output of the generator P_{cp} is equal to:

$$P_{cp} = W_0 \cdot f, \tag{29}$$

where f – frequency of observing discharge pulses, Hz.

The average charging current of the capacitor bank I_{cp}:

$$I_{cp} = C \cdot U_0 \cdot f, \tag{30}$$

Power consumption of the charger P_{nom} is equal to:

$$P_{nom} = \frac{P_{cp}}{\eta}, \tag{31}$$

where η – coefficient of useful action of the charging circuit (in our case, we accept the value η from 0.7 to 0.8).

Based on the average charging current of the capacitor bank I_{cp} and power consumption P_{nom} a standard rectifier transformer is selected, on the basis of which the GIS is laid out.

In order to evaluate the electrical characteristics of the GIS during discharge, it is necessary to consider the transient process of discharge of the liquid metal capacity storage device [9]. Since the full calculation of transient processes in GIS is extremely cumbersome, let's limit ourselves to the simplified equivalent circuit of the discharge circuit presented in (Fig. 14), which allows us to calculate the necessary discharge characteristics of high-voltage equipment.

Since the capacitor battery will work on an inductive load in the oscillating discharge mode, since the melt is a medium with high conductivity, the dependence of the discharge current on time I(t) can be represented in the form of a decaying sinusoid:

$$I(t) = \frac{I'}{\sqrt{1-\gamma^2}} \cdot exp(-\gamma \cdot t) \cdot sin(\sqrt{1-\gamma^2} \cdot t), \quad (32)$$

$$I' = U_0 \cdot \sqrt{C/L}, \quad (33)$$

$$\gamma = 0{,}5 \cdot R \cdot \sqrt{C/L}, \quad (34)$$

where R is the active resistance of the discharge circuit, Ohm. R=Rdzh+Rp+Pрозп+Рпр – active resistance of the accumulator, discharger, fuse and connecting wires, Ohm;

L– the inductance of the discharge circuit, Hn. L=Lzh+Lp+Lрозп+Лпр – internal inductance of the accumulator, inductance of the discharger, own inductance of the melt and connecting wires.

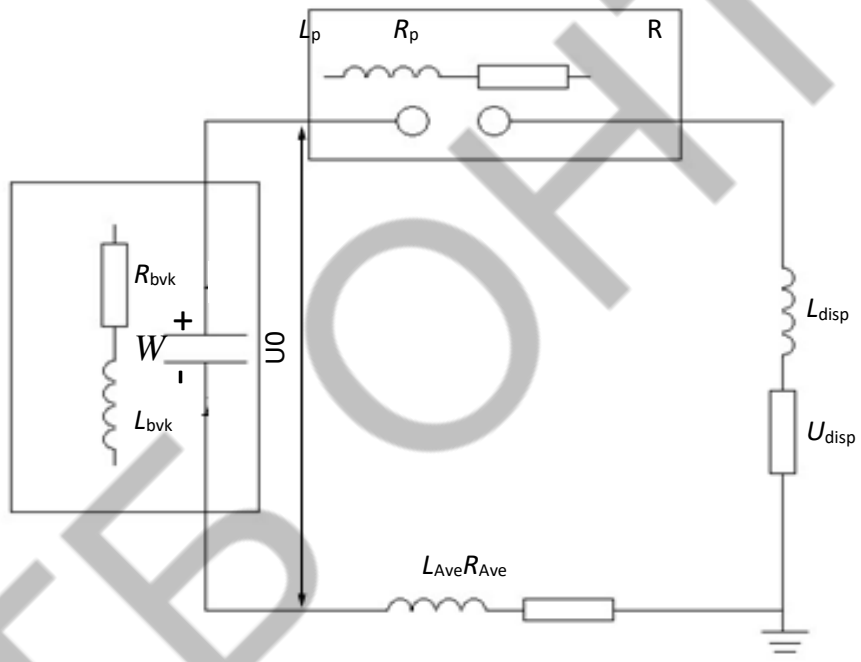


Fig. 14 - Equivalent circuit diagram of the GIS discharge circuit: BVK - battery of high-voltage capacitors; Lbvk – internal inductance of the storage device; Rbvk – active resistance of the accumulator; P - air spark arrester; Lp - inductance of the arrester; Rp – active resistance of the arrester; Lrozp – intrinsic inductance of the melt; Rrozp – melt resistance; Lpr - inductance of connecting wires; Rpr – active resistance of connecting wires.

The maximum possible current amplitude at discharge Imax:

$$I_{макс} = \frac{U_0}{\sqrt{\frac{L}{C}}}, \quad (35)$$

Maximum power $P_{макс}$, which develops in the load until the moment of maximum current is determined from the expression:

$$P_{\text{макс}} = 2 \cdot U_0 \cdot \Gamma \cdot \gamma \cdot \exp\left(\frac{-2 \cdot \gamma}{\sqrt{1-\gamma^2}} \cdot \arcsin\sqrt{1-\gamma^2} \right), \quad (36)$$

4.1. Results of aluminum processing of technical purity

With the use of aluminum of technical purity, a study was conducted on the possibility of suppressing transcrystallization (growth of columnar grains from the periphery to the center along the entire cross-section of the ingot or casting) due to the processing of the melt in the solid-liquid state. In this temperature range, the process of formation and growth of solid phase nuclei begins. The peculiarity of the formation of columnar structures is that the process of crystal nucleation begins on a more cooled surface, and the growth process proceeds in the opposite direction to the heat sink, that is, from the wall of the mold to the center of the ingot [10]. As already mentioned, pure aluminum itself is prone to transcrystallization. For a more stable realization of this phenomenon during the experiment, directed heat removal from the crystallizing melt was created artificially. First, the melt was poured into cold molds (without pre-heating to 450 ºC), secondly, the container with the melt was placed on a massive copper platform, which served as both a negative electrode and a refrigerator. The role of the second refrigerator was performed by the upper electrode placed in the melt (electrode system No. 1).

The idea of this study was that crystal nucleation begins in a thin near-surface layer of the melt, through which a pulse of discharge current flows through the skin effect. Due to Joule's release of heat in this layer, it was assumed to give the crystallization process a volumetric character due to the thermal interaction of the current with the crystals that have already formed and the reduction of the temperature gradient across the cross section of the ingot (thermostat model).

(Fig. 15) shows the cooling curve of aluminum near the bottom of the mold, from which it can be seen that the crystallization process proceeds quite quickly, and the region of the solid-liquid state takes from 50 to 55 seconds. Guided by these data, the treatment duration t was varied, with constant energy parameters of the VEO – C=1 μF; U0 = 7 kV; f = 2 Hz; W0 = 25 J; T = 9 μs; Imax = 5 A. The duration of VEO is presented in table 1, and the temperature interval is indicated by points on (Fig. 15, see the appendix).

The macrostructure of the obtained ingots is characterized by the presence of a well-defined lower zone of columnar crystals and a less pronounced upper zone. The central part of the samples is the equiaxed grain zone. VEO contributes to the narrowing of the lower columnar zone and the grinding of macrostructures, although it was not possible to completely suppress the directed grain growth.

Table 1

Duration of VEO at different temperature intervals

No. sample	1	2	3	4
τ, with	40	80	60	100
Temperature interval (Fig. 14)	AV	AC	DV	DS

The macrostructure improves as the processing interval increases, when the VEO starts slightly above the melting temperature and partially captures the solid state region. This is quite evident, since the crystallization process is non-equilibrium and the true state of the metal may not correspond to the temperature readings.

The analysis of experimental data shows that in order to completely prevent columnar crystallization, it is necessary to increase the power of action not only due to the current strength, but, first of all, due to the frequency of current pulses, comparing it with the linear growth rate of the interfacial surface. In other words, the frequency of the pulses should be such that each subsequent pulse "melts" the thin bases of the crystals that appear on the walls of the mold, preventing their fixation and growth.

Table 2

Indicators of the macrostructure of aluminum

No. sample	control	1	2	3	4
Height of the zone of columnar crystals, mm	35	30	22	21	22
Diameter of columnar grains, mm	5,6	4.7	4.3	3.7	3.7
Diameter of equiaxed grains in the center, mm	5.7	4.7	4.2	3.6 (dendrites)	2.7 (dendrites)

4.2. Results of AK7h alloy processing

AK7ch alloy was processed, using a high-voltage source GIS 12-18/0.25 and two electrode systems: electrode system No. 1 and No. 2. To determine the time to remove overheating of the melt and the temperature-time interval of processing, the cooling curves of the melt were recorded in advance. (Fig. A.1 Appendix A) presents thermograms taken in the center and near the wall of the mold, which allow us to see that the temperature gradient across the cross section of the crystallizing ingot is only a few degrees, that is, the melt crystallized as a single entity. Based on the cooling curve, a temperature of 6200C and duration were selected for the start of processing τ= 5 min., which corresponded to the crystallization interval of the primary a-phase. Conducting a preliminary thermographic analysis also made it possible to establish the chemical composition of the alloy: 6.71% Si; 0.14% Mg; <0.2% Mn; 0.11% Cu; 0.26% Zn; <0.1% Ni; < 0.1 Fe.

The VEO parameters given in Table 3 allow us to note the use of a small current passing through the melt and a slight decrease (up to0.7 mm) of the thickness of the skin layer.

Table 3

VEO parameters of AK7h alloy

Sample No	1	2	3	4
Capacity*WITH*, μF	0.25	0.25	0.25	0.25
High-voltageU_0, kV	12	12	12	12
The frequency of compliance with impulses*f*, Hz	1	6	1	6
Stored energyW_0, J	18	18	18	18
Discharge current period*T*, mks	5	5	5	5
The amplitude of the discharge current*Imax*, kA	4	4	4	4
No. electrode system	2		1	

The structure of ingots obtained as a result of VEO is dense, dendritic. The results of the metallographic analysis (table.4.) show that the VEO of the crystallizing melt, in contrast to processing in the quasi-two-phase region, has a positive effect on all structural components already at such a small energy in the pulse as W0 = 18 J (respectively, a small force current). The structure of the ingots is dense, dendritic throughout the cross-section. However, after VEO there is a tendency to the formation of a more dispersed and less oriented dendrite. After processing, particles of brittle eutectics are also crushed, needles of iron phases are transformed.

Table 4

Parameters of the microstructure of AK7ch alloy samples

Sample No	Size grains, μm	Eutectic volume, %	The length of the particles*Si* in the eutectic, μm	Iron phase
Control	170	19	108	needles 100 μm long
1	166	22	97	needles 60 microns long
2	133	21	87	inclusion of a compact form with a diameter of 36 μm
3	138	21	95	inclusion of a compact form with a diameter of 50 μm
4	133	20	76	inclusion of a compact form with a diameter of 85 μm

4.3. Results of AK7 alloy processing

AK7 alloy was treated using GIS and three different electrode systems as a high-voltage source (table. 5). In addition, the current strength and the frequency of observing pulses varied. Based on the cooling curves (Fig. 16), a temperature of 620 0C was assumed for the beginning of processing, as well as for the AK7h alloy, and the duration was τ= 5 min. The use of laboratory GIS made it possible to study the influence of higher energy regimes of VEO on the structure and properties of the alloy. Conducting a chemical analysis of the alloy (7.0% Si; 0.23% Mg; 0.22% Mn; 1.45% Cu; 0.34% Zn; 0.04% Ni; 0.68% Fe) made it possible to determine several higher iron content and increased copper content. On the one hand, the composition of these elements meets the requirements of DSTU 2839-94, on the other hand, the higher iron content made it possible to study in more detail the effect of VEO on harmful ferrous phases.

Table 5

VEO parameters of AK7 alloy

Sample No	Processing parameters					
	WITH, μF	U_0, kV	*f*, Hz	W_0, J	*T*, mks	*Imax*, kA
Electrode system No. 1						
control	–	–	–	–	–	–
1	1	7	2	25	9	5
2	1	7	6	25	9	5
3	1	20	2	220	9	16
Electrode system No. 2						
control	–	–	–	–	–	–
4	1	7	2	25	9	5
5	1	7	6	25	9	5
6	1	20	2	220	9	16
Electrode system No. 3						
control	–	–	–	–	–	–
7	1	7	2	25	9	5
8	1	7	6	25	9	5
9	1	20	2	220	9	16

Diagrams are presented in (Fig. 17, see the appendix) that allow analyzing the influence of processing parameters and electrode systems on the granular structure. It can be seen that the control ingots contain a large, almost equiaxed grain along the entire section. Increasing the power of the current action on the crystallizing metal, in comparison with the VEO of the AK7h alloy, where the degree of grain grinding was 1.3 times, led to grinding of the grain structure from 1.5 to 3 times. Moreover, the most effective in this regard is electrode system No. 2 - two electrodes immersed in the melt. It should also be noted that, despite the fact that the depth of immersion of the electrodes was all5 mm, changes in the structure are observed over the entire cross-section of the ingot. With an increase in the power of action, the extent of changes in the structure increases. However, it is not possible to separate the contribution of the frequency of pulses and the current strength at this stage, since samples No. 4 and No. 5 correspond to the same power and, as we can see, the degree of change in the structure is the same.

V.CONCLUSIONS

1. The analysis of existing scientific works, patents and literature in the field of non-bake metal processing allows us to single out several main areas, among which the least researched and promising is pulse-periodic current processing.

2. The electrical characteristics of the discharge current pulse in two phase states were studied: liquid and liquid-solid. The frequency range (from 85 to 115 kHz) in which the maximum of the spectral density is concentrated is revealed. It was found that as the temperature of the melt decreases, the maximum of the spectral density shifts to lower frequencies and the reactive component of the resistance changes.

3. High-voltage electropulse processing of the melt in the crystallization interval, compared to processing in the liquid state, has a significant effect on the structure of aluminum of technical purity, which hardens under the conditions of directional heat removal. With VEO using Imax = 5 kA and f = 2 Hzachieved reduction of the zone of columnar crystals by 1.5 times and grinding of equiaxed dendrites by 2 times. During VEO of the hardening metal, there is a steady dependence of the parameters of the structure and properties on the power of action: with an increase in the power of action on the hardening Ak7ch and AK7 alloys, the granular structure is crushed, the degree of dendrite disorientation and the degree of compaction of brittle components increases, and plasticity increases.

The scheme of processing with two submerged electrodes is preferred for VEO of a hardening metal.

The proposed mechanism of high-voltage electropulse processing, effective in the processing of crystallizing metal, with which the main contribution to the change in the state of the melt, structure and properties of the metal can be attributed, namely, the effect of VEO on the rate of formation of crystallization centers, and the electrotechnical equipment for the implementation of this mechanism has been developed.

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APPENDICES

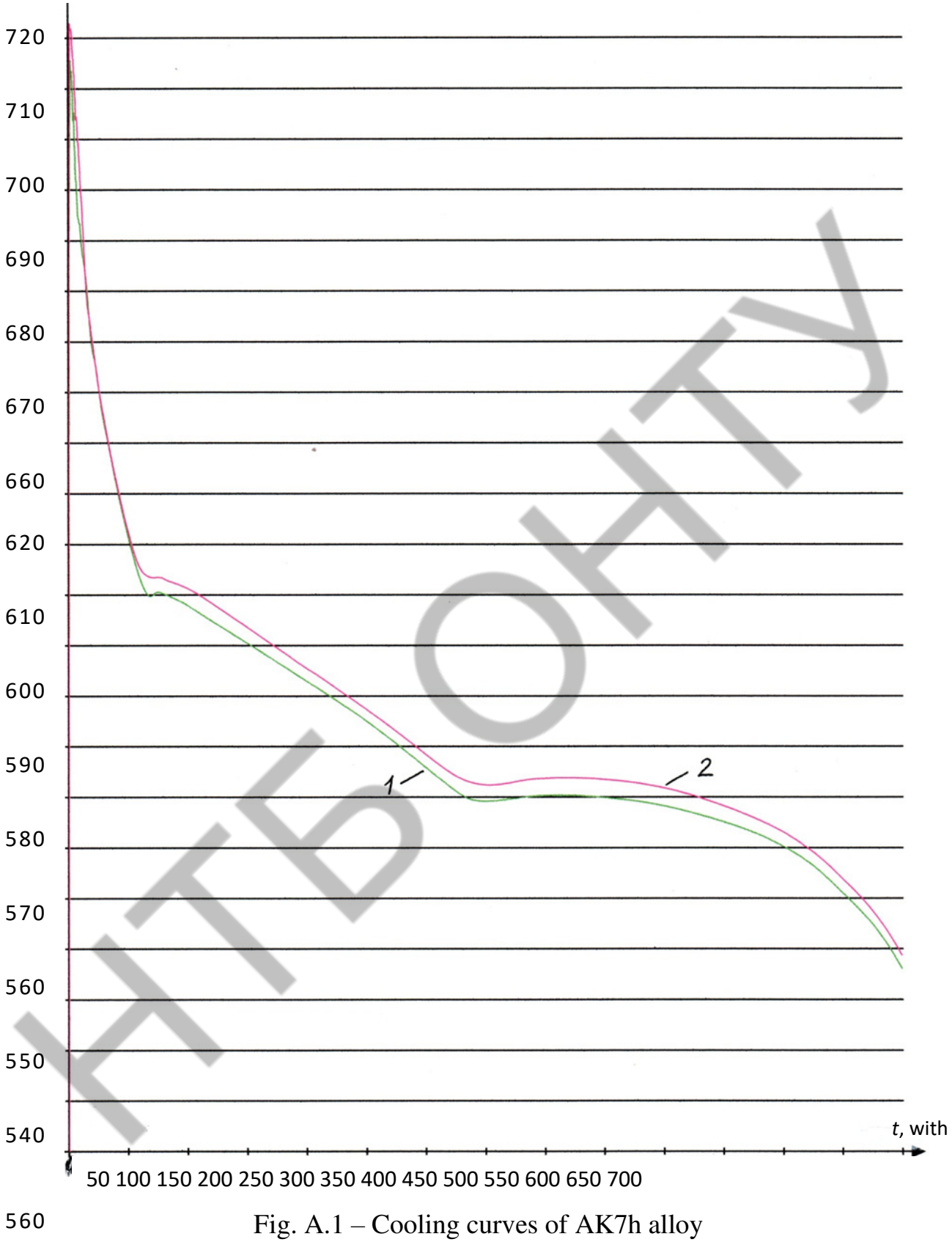
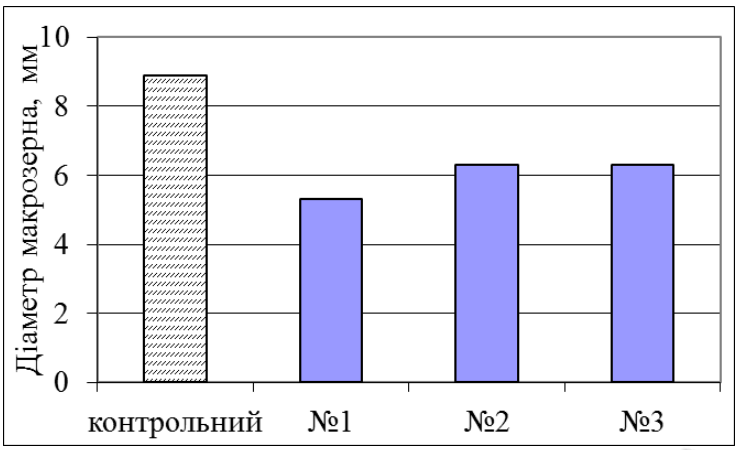


Fig. A.1 – Cooling curves of AK7h alloy
1– near the wall of the form; 2– in the center



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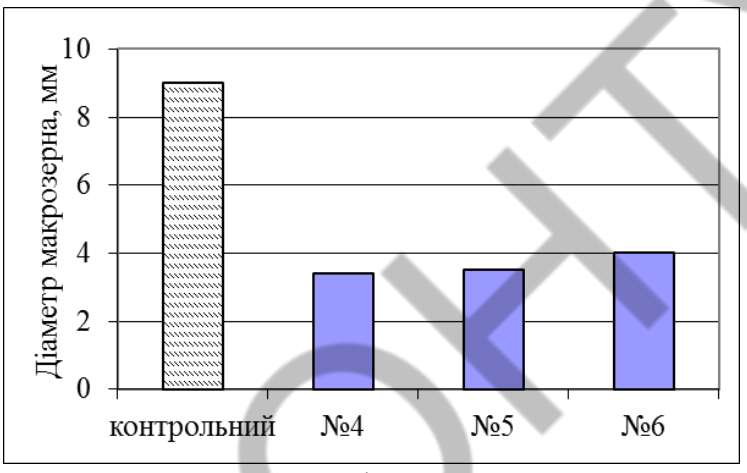

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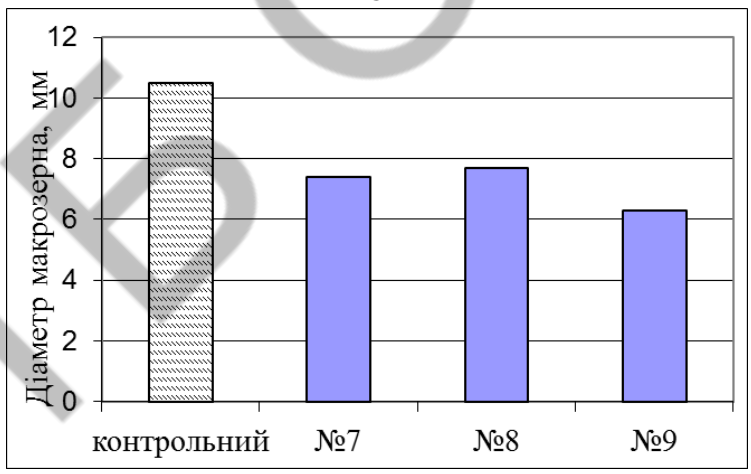


in

Fig. 17 – Influence of VEO on the macrostructure of the AK7 alloy: a, b, c - electrode systems No. 1; number 2; No. 3 respectively

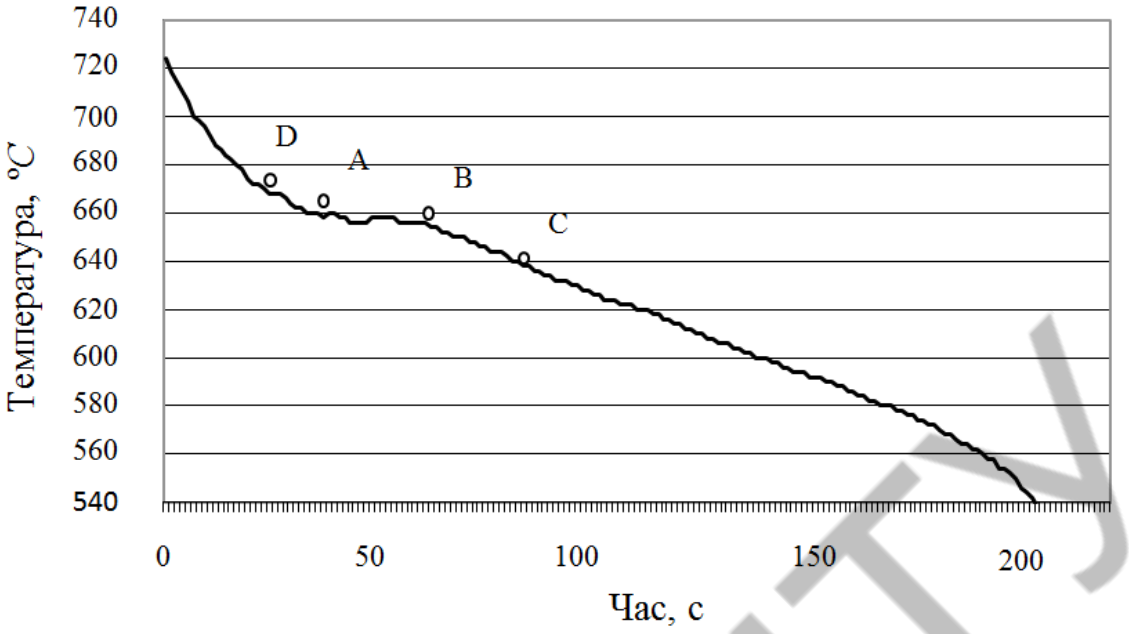
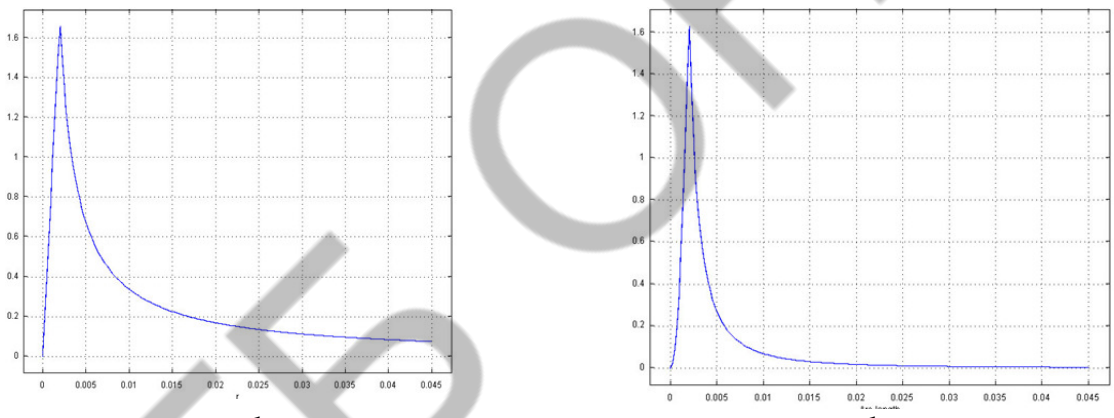


Fig. 15– Aluminum cooling curve near the bottom of the mold (near the copper cooler)



and b

Fig. 12 – Distribution of the magnetic field and pressure along the melt mirror
a – distribution of the magnetic field along the melt mirror; b – magnetic pressure distribution along the melt mirror

OPTIMIZATION OF THE LOCAL MARINE ENERGY SYSTEM WITH DIESEL-GENERATORS

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Abstract. *Maritime shipping sources 3% of global greenhouse gas emissions and heavily depends on fossil fuels. Decarbonizing this sector requires a joint approach involving the global shipping industry, governments, and international organizations. A diesel generator is the main source of electricity for marine installations. The cost of electricity in local systems for maritime shipping and sea floating platforms equipped with diesel generators depends primarily on the cost of primary fuel for diesel generators. An algorithm for the optimal redistribution of generators operating in parallel with different rated power and consumption curves of specifi fuel consumption B from power P was developed. It was suggested to specify fuel consumption taking into account a non-linear curve and divided into several subintervals. An algorithm for optimizing the operation of two generators are presents. A program in the Matlab programming language was developed based on it. The specific fuel consumption for the considered local system was 0,2-1,63% when using the optimal distribution algorithm relative to the uniform power distribution. The developed algorithm can be used for the following purposes: evaluation and research of optimal energy generation; carrying out preliminary calculations of fuel consumption of diesel generators. From an environmental point of view, the use of optimization algorithms reduces fuel consumption and leads to a reduction in CO_2 emissions.*

Keywords: *Specific fuel consumption, local system, diesel-generator, non-linear programming*

I. INTRODUCTION

Maritime shipping sources 3% of global greenhouse gas emissions and heavily depends on fossil fuels. The maritime sector, which accounts for more than 90% of world trade, is regarded as the basis of the global economy. Emissions are expected to increase further as this business expands. Coordinated and comprehensive actions are essential if the shipping industry tends to move towards zero emissions. Decarbonizing this sector requires a joint approach involving the global shipping industry, governments, and international organizations [1].

Optimal planning of generation of available generators to minimize total fuel consumption while meeting load demand and operational constraints in power consumption of offshore drilling rigs plays an essential role in improving specific power and oil rig efficiency.

Local systems based on diesel generators provide electricity. Such a local system is a multi-purpose system dealing with technical, economic, and environmental issues.

The main goals of local system control systems are optimization of operation, power supply planning, and system reliability.

A diesel generator is the main source of electricity for marine installations. The specific fuel consumption of marine engines ranges from 155 to 200 g/kWh at optimum load settings, typically around 85% of the maximum continuous load (MCL). Specific fuel consumption increases sharply when approaching at low power (30% P_{max}) and especially at idle (7% P_{max}).

Manufacturers do not recommend operating diesel generators at a load below 30-40% pu, at idle, as the generator may overheat. Fuel consumption of the diesel generator at idle entails economic inefficiency, as the cost of 1 kW of electricity will be quite high.

Incorrectly calculated power consumption can cause the diesel engine to work either with an overload (diesel machine manufacturers, as a rule, stipulate permissible short-term overloads within the range of 110% during 1 hour) or remain underloaded. In the first case, the engine life will reduce along with a decrease in efficiency (up to 20%). In the second case, the diesel generator operates in non-optimal modes, and its main components wear out quickly.

The total fuel consumed by the local maritime shipping assurance system based on diesel generators shall be minimized as the main target function.

II. LITERATURE ANALYSIS

Obtaining the equity of load capacities and power generation is a problem of nonlinear optimization [2-5].

Accurate simulation of specific fuel consumption is an urgent task for the optimal planning of generator operation when fuel consumption is the optimized function.

The study [2] features a nonlinear curve of the dependence of fuel consumption on power with polynomial functions of the third degree for diesel engines. This study suggests dividing the dependence into several intervals, which are described by different functions, to approximate fuel consumption to real rates.

Simulation of specific fuel consumption is usually carried out using polynomials of the second and higher orders, which, in turn, results in a higher error percentage. The study [3] suggests the use of cubic spline interpolation, which allows accurate simulation of the curve with minimal error.

Improving the energy efficiency of a local system based on diesel generators requires solving the issue of optimizing operating modes using the reduction of primary fuel consumption of diesel generators as an optimization criterion [4].

Algorithms for controlling the operation of diesel generators are based on the equation of maintaining the system energy balance.

General algorithms and methods used to manage the energy of local systems can be classified into two main categories: classical methods (methods of linear and non-linear programming) and AI methods (methods of fuzzy logic and neural networks). Besides, control algorithms can be a combined form of these methods [4,5].

An algorithm rapid change in the generator power level and power consumption power in to increase energy efficiency when powered by one DG is suggested in 1.

The need for parallel operation of several generators is essential to increase power, ensure increased power supply reliability, uninterrupted power supply for the main power source maintenance period, and compensate for the increase in power consumption by the connected load.

II. OBJECT, SUBJECT, AND METHODS OF RESEARCH

Object primary fuel consumption in diesel-generator.

Subject local maritime system.

Methods of research: mathematical methods for approximating characteristics, methods of theoretical foundations of electrical engineering, non-linear programming method for optimization.

IV. RESULTS

Accurate modeling of SFC is an important issue in the optimal scheduling of diesel-generators with fuel consumption as optimization function. Table 1 shows the specific fuel consumption as a part of the total power of the considered generator (Wärtsilä 16V26A (P=5200 kW), Wärtsilä 8V26A(P=3900kW)) [2,3].

Table 1 shows that there are no specific fuel consumption data for starting the generator (0% of the nominal load of the diesel generator).

Table 1 – Specific Fuel Consumption for Diesel Generators at Different Loads

	Specific Fuel Consumption, (g/kWh)
Load (pu)	**Wärtsilä 16V26A**
0	289
0,25	233,12
0,50	201,00
0,75	192,98
0,85	195,20
0,90	195,51
1,00	196,55

The value of missing data can be determined by extrapolation. Missing data can be extrapolated using 2nd- and 5th-degree polynomials, cubic spline function, and data from Table 1. In reality, a diesel generator's specific fuel consumption curve shows a maximum specific fuel consumption at the start. Therefore, polynomials of higher degrees cannot be used for extrapolation. At the same time, the use of polynomials of lower degrees will result in a more significant error. Using a cubic spline function makes it possible to avoid this.

The specific fuel consumption at zero load or diesel generator start, calculated using a cubic spline, is

Mathematical equations (1) - (7) can be used to calculate the numerical value of the specific fuel consumption at any given load of the diesel generator [2,3]:

I subinterval for $0 \le p_j < 0{,}25$

$$B(p_j) = 2{,}9512(p_j)^3 + 187{,}866(p_j)^2 + 270{,}67\,p_j + 289 \quad (1)$$

II subinterval for $0{,}25 \le p_j < 0{,}5$

$$B(p_j) = 2{,}9512(p_j - 0{,}25)^3 + 190{,}08(p_j - 0{,}25)^2 - 176{,}184(p_j - 0{,}25) + 233{,}12 \quad (2)$$

III subinterval for $0{,}5 \le p_j < 0{,}75$

$$B(p_j) = 7{,}0041(p_j - 0{,}5)^3 + 192{,}293(p_j - 0{,}5)^2 - 80{,}591(p_j - 0{,}5) + 201 \quad (3)$$

IV subinterval for $0{,}75 \le p_j < 0{,}85$

$$B(p_j) = -1442{,}4(p_j - 0{,}75)^3 + 197{,}546(p_j - 0{,}75)^2 + 16{,}869(p_j - 0{,}75) + 192{,}98 \quad (4)$$

V subinterval for $0{,}85 \le p_j < 0{,}9$

$$B(p_j) = 1940{,}1(p_j - 0{,}85)^3 + 235{,}158(p_j - 0{,}85)^2 + 13{,}10(p_j - 0{,}85) + 195{,}2 \quad (5)$$

VI subinterval for $0{,}9 \le p_j < 1$

$$B(p_j) = 67{,}134(p_j - 0{,}9)^3 + 55{,}8598(p_j - 0{,}9)^2 + +4{,}1427(p_j - 0{,}9) + 195{,}51 \quad (6)$$

VII subinterval for $1{,}0 \le p_j < 1{,}1$

$$B(p_j) = 67{,}134(p_j - 1)^3 + 76(p_j - 1)^2 + 17{,}328(p_j - 1) + 196{,}55 \quad (7)$$

A fuel consumption curve (Fig. 1), showing how much fuel is consumed to generate a specific power value using a Wärtsilä 16V26A diesel generator, was constructed based on expressions 1-7.

The algorithm suggested in [6] was improved to optimize the local system based on diesel generators for the marine sector (offshore drilling rigs). In this algorithm, generator power graphs were described by a single function over the entire power variation interval. It was suggested to specify fuel consumption taking into account expressions (1-7).

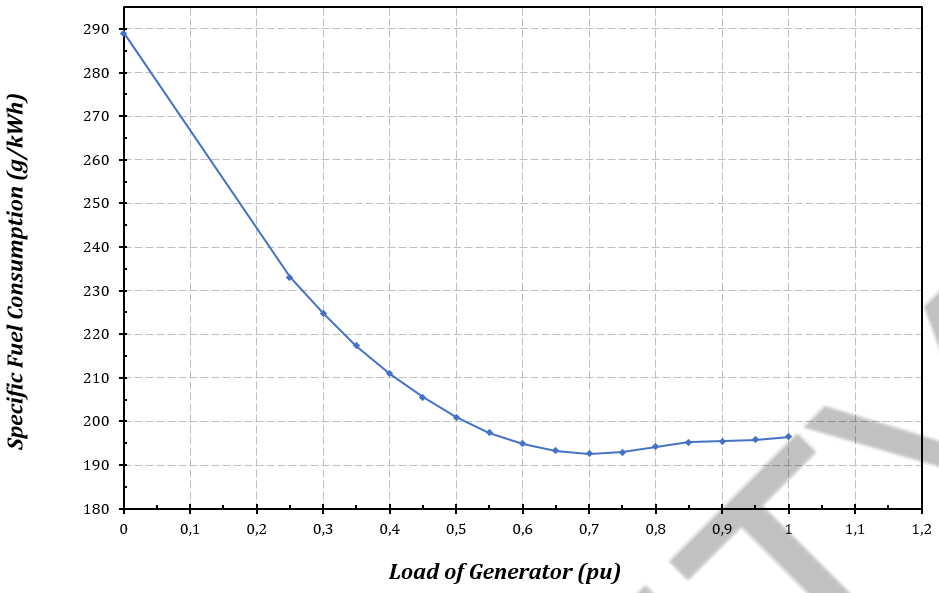


Fig. 1. Specific fuel consumption B of the diesel generator at P_{load} different loads.

This algorithm sets the required values of diesel generator capacities at each time interval taking into account the previous values of generator capacities to ensure the current P_H value.

The scheme of the local system is shown in fig. 2. It consists of two generators and load.

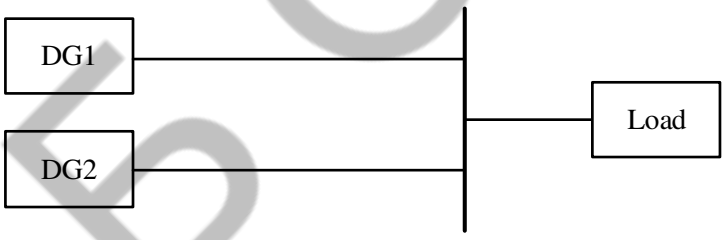


Fig. 2. Scheme local energy system

As shown in the figure, a tidal turbine installation, diesel generators and energy storage battery are used to power the offshore drilling rig in stand-alone mode of operation. The specific fuel consumption of diesel engines is usually simulated using polynomials of the second and higher order.

When the load changes at each time interval, the i function of finding the minimum is the sum of primary fuel consumption:

$$B_{i\min} = B_1(P_{1(i-1)} + \Delta p_{1i}) + B_2(P_{2(i-1)} + \Delta p_{2i}) \quad (8)$$

where $\Delta p_{1i}, \Delta p_{2i}$ are power values by which the power of each generator shall be changed (increased or decreased).

Algorithm for optimizing the operation of two generators

Step 1. Set initial conditions:

- curves of consumption of primary fuel B from power P for each generator separately $B_1(P)$, $B_2(P)$ in the form of a continuous function
- expressions that describe the dependence of $B_1(P)$, $B_2(P)$ on different intervals for revised calculations.
- initial power values of each generator P_{10}, P_{20}. In relative units.

Step 2. Set the current value of the load power of P_{loadi} of i interval.

Step 3. Calculate the required value of the load power change relative to the previous one:

$$\Delta P_i = P_{loadi} - (P_{1(i-1)} + P_{2i-1}).$$

Step 4. Condition check:

$$\Delta P_i = 0$$

if **Yes**, then the calculation goes to **Step 2**; if **No,** then the calculation shall be performed further.

Step 5. Calling the subroutine to calculate the minimum value of primary fuel consumption (8).

Calculate the function under the following limitations:

- the sum of power by which the power of the generators changes shall be equal to the load change calculated at **Step 2.**

$$\Delta p_{1i} + \Delta p_{2i} = \Delta P_i$$

- the power change of each generator shall be within the following limits

$$-\Delta P_i \le \Delta p_{1i} \le \Delta P_i$$

$$-\Delta P_i \le \Delta p_{2i} \le \Delta P_i$$

- the power of the generator shall not exceed its maximum power

$$(\Delta p_{1i} + P_{1(i-1)}) \le P_{1\max}$$

$$(\Delta p_{2i} + P_{2(i-1)}) \le P_{2\max}$$

Step 6. Calculation of power that shall be installed to obtain minimum consumption:

$$P_{1i} = P_{1(i-1)} + \Delta p_{1i},$$

$$P_{2i} = P_{2(i-1)} + \Delta p_{2i}.$$

Step 7. Clarify fuel consumption. Determine the value of the fuel using the specified functions (1-7), taking into account the power obtained in **Step 6.**

Step 8. Set initial conditions for the next calculation. The obtained power values are the initial conditions for calculations during the next interval.

Repeat the calculation from **Step 2.**

At the same time, the function shall be calculated under the following limitations:

$$\begin{cases} \Delta p_{1i} + \Delta p_{2i} = \Delta P_{loadi} \\ -\Delta P_{loadi} \le \Delta p_{Gi} \le \Delta P_{loadi} \\ (\Delta p_{Gi} + P_{G(i-1)}) \le P_{\mathrm{G\,max}} \end{cases}$$

where $\Delta P_{loadi} = P_{load(i-1)} - P_{loadi}$ – change of load power, $\Delta p_{\Gamma i}$ – power increase of a single generator.

Wärtsilä 8V26A was chosen as the second diesel generator. Its consumption curve is shown in Fig. 3 in relative units from the Wärtsilä 16V26A maximum power.

*B1(p)*and *B2(p)* are represented as polynomials:

$$B1(p) = -68{,}584\,p^3 + 271{,}13\,p^2 - 294{,}03\,p + 289{,}58$$

$$B2(p) = 155\,p^3 + 129{,}93\,p^2 - 37{,}8\,p + 225{,}63$$

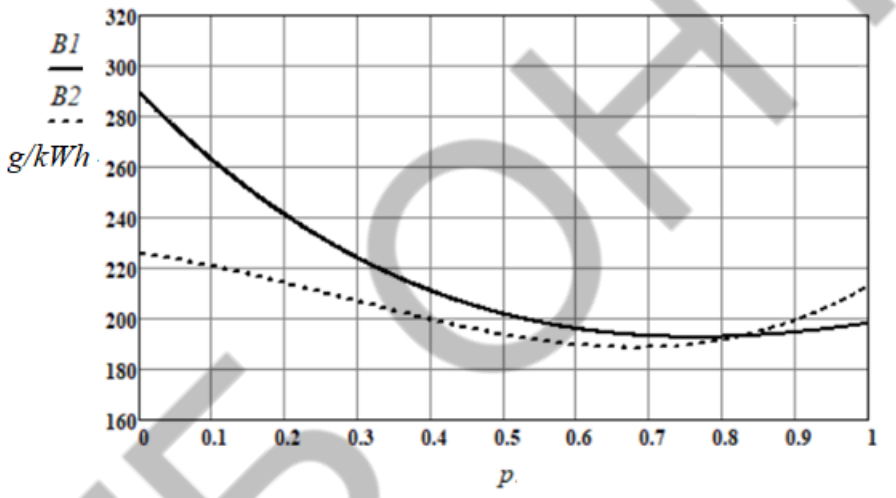


Fig. 3. The power load P_{load} (pu)

Consider for the daily load diagram presented in the form of a step graph during 12 *T* intervals (every 2-hour) (Fig. 4).

Calculations of primary fuel consumption of diesel generators were carried out according to the algorithm developed by the program in the Matlab programming language.

Figure 5 shows the fuel consumption *B1(p)* for the graph in Fig.3 and *B11(p)* for the graph in Fig.1. Fuel consumption is shown in Fig. 6. Power distribution diagrams for each generator are shown in Fig. 7-8.

Determining the final consumption, the cost of fuel is calculated using functions (1-7).

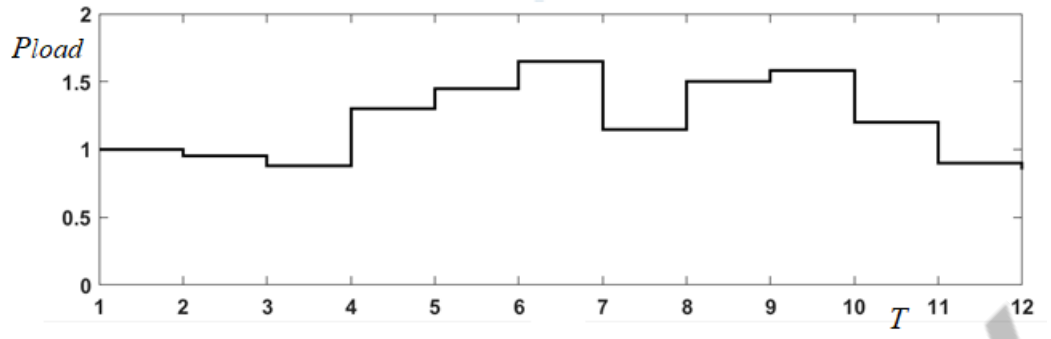


Fig. 4. The power load P_{load} (pu)

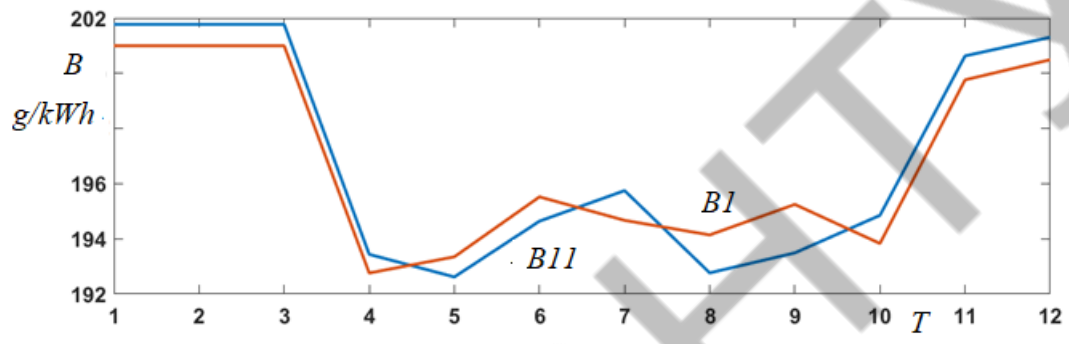


Fig. 5. Fuel consumption

A curve in Fig. 6 was constructed to evaluate the optimization. It corresponds to the consumption of primary fuel with a uniform distribution of power according to the following expression:

$$B_{neopt} = \sum_{i}^{n} B_i \left(\frac{P_{Hi}}{n} \right)$$

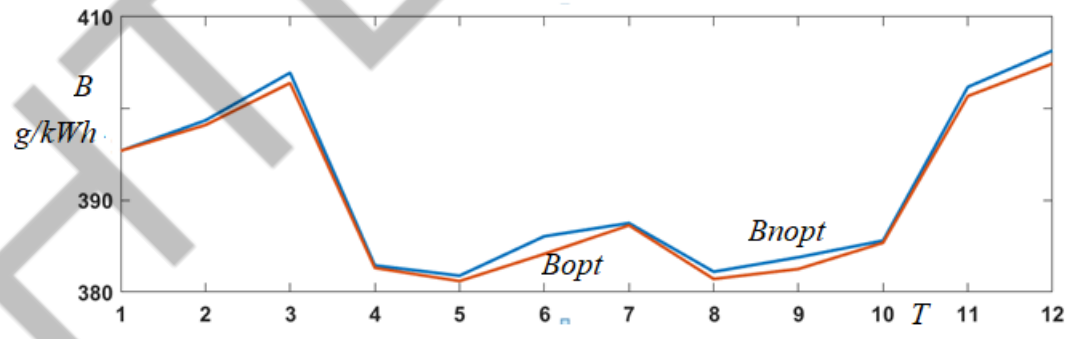


Fig. 6. Total specific fuel consumption

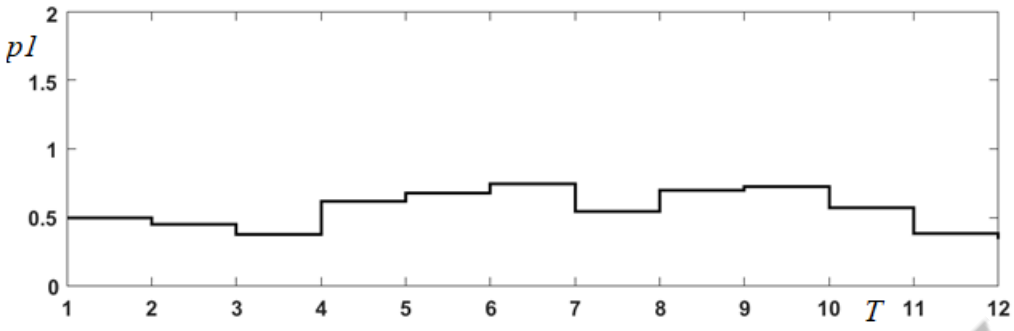


Fig. 7. Optimal power distribution for I generators

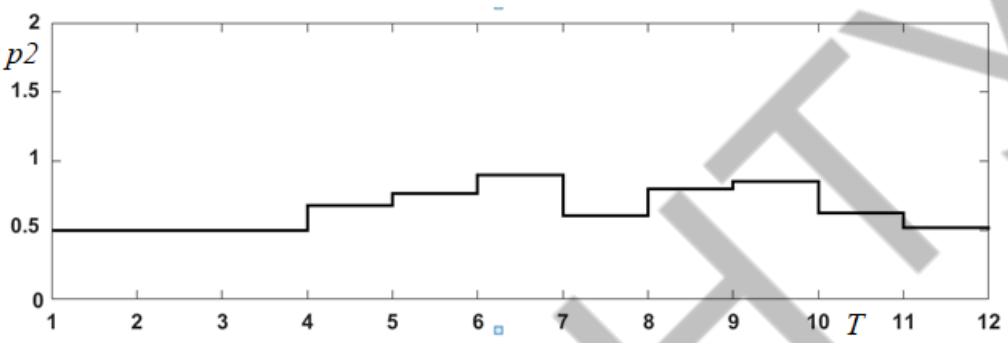
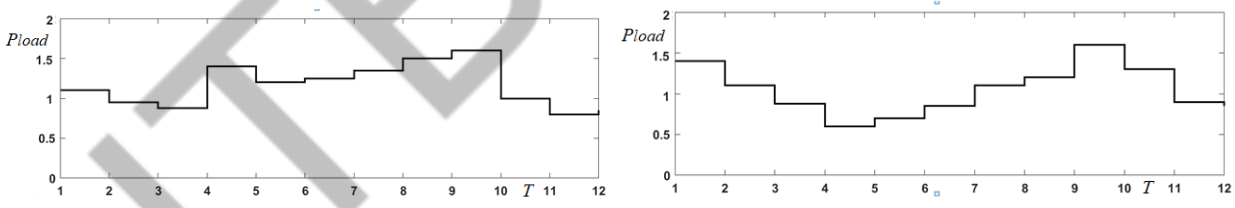


Fig. 8. Optimal power distribution for II generators

A comparison of the results of the algorithm taken as a basis with the approximated revised information was performed.

The results were entered into Table 2 for two options for load power curves (fig.1 fig.9 a and b). $B_{\%},\%$ – percent of fuel consumption reduction, Mean values B_{nopt} *and* B_{opt}



a b

Fig. 9. The power load P_{load} (pu)

Table 2. Optimization results

№	fig	B_{nopt}, g/kWh	B_{opt} g/kWh	$B_{\%},\%$
1	(fig.1)	4696	4687	0,2
2	(fig.9a)	4783	4705	1,63
3	(fig.9b)	4792	4752	0,85

When using the optimal algorithm into account a non-linear curve and divided into several subintervals., the average value of $B_{\%}$ is 0.2% – 1,6% (depends on load schedules) relative to the uniform power distribution.

The use of the algorithm and the program based on it will allow for the following:

- to reduce the cost of electricity for offshore drilling rigs by lowering the costs of fuel purchase and delivery;
- performing preliminary calculations of diesel generator fuel consumption as part of local systems for given load capacity diagrams.

V. CONCLUSIONS

The optimization algorithm and a program for analyzing and optimizing primary fuel consumption when distributing power between diesel generators based on it with revised calculations of fuel consumption made it possible to obtain more accurate consumption values. The economic impact of implementing optimization can be achieved by reducing the current fuel consumption and costs for its delivery. From a technological perspective, there is a reduction of the expenses for the use and delivery of primary fuel and losses during the production, transmission, and redistribution of energy. From an environmental perspective, the application of optimized algorithms and the use of renewable energy sources leads to a reduction in CO_2 emissions and the decarbonization of the marine sector.

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DETERMINATION OF WAYS OF PROTECTING CRITICAL OBJECTS OF THE ENERGY COMPLEX AGAINST AIR STRIKES THROUGH THE JOINT APPLICATION OF DIFFERENT FORCES AND MEANS

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Abstract. *The experience of the Russian-Ukrainian war in 2022 once again confirmed to the whole world that for terrorist organizations and terrorist countries, which are unable to achieve victory on the battlefield, the main thing is to strike critical objects of the state's infrastructure: the energy complex, bridges, etc.*

In this context, the task of ensuring comprehensive protection of critical state infrastructure objects from air strikes is urgent.

The study of the subject area of compatibility and the combined use of means of physical influence (MPI) and means of radio-electronic influence (REI) theoretically assumes the presence of abstract objects with their connections and interconnections, which are created for the purpose of an idealized description and study of possible situations and order of actions for them.

This work examines the issue of increasing the effectiveness of protecting critical facilities of the energy complex (CFEC) from air strikes due to the combined use of anti-aircraft fire and anti-aircraft fire protection, methods of determining the locations of physical impact means, which allows to evaluate the expected results of combined actions, as well as to develop scientifically based recommendations for their effective combined use, which is news.

Means of physical influence may include firearms that are in service in the armed forces and other law enforcement agencies, interceptor drones, rifles with nets and other means.

Means of radio-electronic influence may include means of radio-electronic warfare, electromagnetic guns and other means based on fundamentally new physical principles of operation.

Keywords: *critical objects of the state's energy complex, compatibility, means of physical influence, means of radio-electronic influence, means of air attack.*

I. INTRODUCTION

In the world, a significant number of dangerous critical objects are located on the territory of most states. The degree of danger of the object is established based on the share of the civilian population and the territory that fall into the zone of possible neutralization in the event of an accident at a dangerous object. The results of terrorist acts during 2019-2022 in the world and the course of the Russian-Ukrainian war show that the most dangerous objects today are the objects of the energy complex.

One of the most famous examples of the use of drones to attack land and sea targets was the events in the Persian Gulf. On September 14, 2019, the Yemeni Houthis attacked Saudi Aramco's oil facilities in Abqaiq and Khurais (Saudi Arabia) with the

help of UAVs, which are at a distance of at least 900 km from Yemen. The result of the attack was causing quite significant financial losses to oil companies.

In just nine months of 2022, more than 184 cruise missiles and more than 95 unmanned aerial vehicles, including more than 70 Iranian Shahed-136 kamikaze drones, were fired at Ukrainian cities where critical facilities of the state's energy complex were located. According to the calculations of the world's leading economists, the economic damage caused by these strikes to the state amounts to more than 300 billion dollars.

It is because of this that it is necessary to define measures and develop certain methods to protect the CFEC from air strikes. Ukraine has sufficient experience in the organization of air defense of troops and certain important objects, including nuclear energy objects, against conventional means of defeating air bases. At the same time, the development of unmanned aviation and, first of all, kamikaze drones [1, 2] opened up new opportunities for the use of air attack means (AAM) in relation to critical objects, including critical objects of the energy complex.

The leading countries of the world have focused their efforts in the protection of critical objects on a combination of the use of physical and electronic means of influence, which is new for the defense forces of Ukraine and involves studying the issue of the compatibility of the means of physical influence and means of radio-electronic influence available in our country to protect CFEC from actions of AAM. The study of these issues will allow to assess the expected effectiveness of joint actions, as well as to develop scientifically based recommendations for their application.

II. LITERATURE ANALYSIS

In solving the problem of protecting critical objects of the energy complex from air strikes, three directions can be distinguished:

1. Determination of the list of critical objects of the energy complex of the state that require protection from air strikes.

2. Determining the composition of the forces and means that must be involved to protect the CFEC from air strikes.

3. Deployment of specified forces and means to protect selected critical facilities of the energy complex. Evaluating the effectiveness of the combined use of various forces and means.

Legislative initiatives and scientific works, which were reflected in the publications of specialists in this area, are devoted to these issues.

The Law of Ukraine “On Critical Infrastructure” 1882-IX dated 16.11.2022 and Resolution of the Cabinet of Ministers of Ukraine dated 09.10.20 No. 1109 “Some Issues of Critical Infrastructure Objects” define the concept of critical infrastructure, the procedure for ensuring its functioning, and a list of these objects. The relevant directive documents of the defense forces of Ukraine determined the composition of the forces and means involved in the protection of specified objects and in the vast majority of these means of protection were stationary anti-aircraft missile complexes of the Air Force of Ukraine. At the same time, the experience of Russian terrorist attacks from the air on the objects of the energy complex of the state proved that in order to ensure the vital activity of the state, the list of objects that are subject to

protection from air strikes should be expanded, and accordingly, it is necessary to involve additional means for protection, which do not belong to the anti-aircraft missile system of the Air Force of Ukraine.

A number of scientific works have been published, dedicated to solving the tasks of joint performance of the tasks of air defense means and means of radio-electronic warfare, for example [3-5], in which the main principles and approaches to determining the possibility of their joint application are formulated, and various options for building air defense units in the area are proposed.

The question of protection of explosive objects was studied in the scientific works of A. Volkov [6] and O. Lezik [7, 8], the question of determining the effectiveness of the use of air defense units and recommendations for their use were considered in the works of M. Yermoshin [9], V. Horodnova [10].

At the same time, the analysis of scientific works shows that they primarily considered the issues of protecting military facilities, such as ammunition depots, the accumulation of equipment from strikes by conventional air-based weapons, a number of problematic issues require further study, there is a need to improve methodological approaches to determining the rational placement of protection means around the protected object, making recommendations and evaluating the effectiveness of the created protection. Therefore, the goal of further research may be to consider the effectiveness of the combined use of physical and electronic means of influence to protect critical facilities of the state's energy complex.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The object of the study is the system of protection of critical facilities of the energy complex of the state.

The subject of the research is the combined use of means of physical influence and means of radio-electronic influence.

The purpose of the work is to evaluate the results of the combined actions of means of physical influence and means of radio-electronic influence during the protection of critical objects of the energy complex from air strikes.

Objectives of the study:

1) analysis of the compatibility of means of physical influence and means of radio-electronic influence;

2) development of a methodology for choosing the place of placement of means of physical influence during the protection of CFEC from air strikes;

3) development of scientifically based recommendations for the effective combined use of means of physical influence and means of radio-electronic influence and their coordination.

Research methods – system analysis, development of methods for choosing the place of placement of means of physical influence, mathematical modeling.

IV. RESULTS

4.1. Determination of the method of choosing the place of placement of means of physical influence during the protection of critical objects of the energy complex from air strikes.

In order to develop a method for choosing the place of placement of MPI during the protection of CFEC from an air strike, it is proposed to use an algorithm (Fig. 1), which consists of procedures and tasks that are performed sequentially, as a result of which proposals are formed for the selection of places of placement of MPI, their number and evaluation results.

The initial data for calculating the distance between the MPI (block 1) are:

– types of AAM that can be applied to the object of protection;

– geographic coordinates of the object of protection and their spatial dimensions;

– the composition of MPI allocated for the protection of the object;

– the maximum efficiency of the use of MPI;

– characteristics that describe the effectiveness of the use of MPI.

The initial data are selected from prepared databases, which are formed in advance or during the preparation of the solution (block 1).

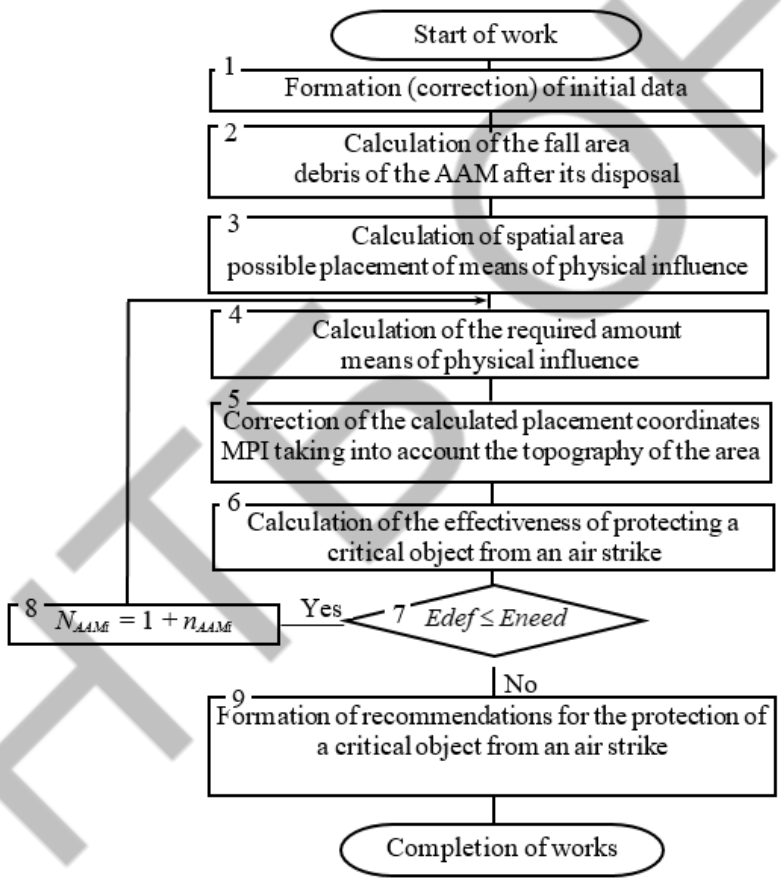

Figure 1. Algorithm for choosing the location of the anti-aircraft missile system during the protection of the object from an air strike

In block 2, the area of fall of the AAM debris after its neutralization is calculated. To perform this task, an existing model [11] is used. The calculation of the area of fall of AAM fragments is carried out in order to determine the required distance of placement locations from the perimeter of the protection object. The analysis of the

results of the simulation of the neutralization of the AAM at all possible flight speeds and altitudes showed that the removal distance of the locations should lie within 1 to 2 km from the protection object.

Among the boundaries that determine the operation of the MPI, the most important place is the range of the AAM from the object of protection, at which the task of its neutralization should be set. This range depends on which means of physical influence the task is set, on the flight height of the AAM and the time of work on detecting and neutralizing the AAM, on the distance of the removal of the neutralization zone beyond the protection object.

The horizontal distance from the object of protection to the boundaries of setting the tasks for the disposal of the AAM is determined by the formulas:

$$d_{\text{d.s.t}} = d_{\text{d.MPI}} + V_{\text{AAM}} \left(t_{\text{d.p.MPI}} + t_{\text{t.n}}\right), \quad (1)$$

where $d_{\text{d.s.t}}$ – the horizontal distance from the object of protection to the boundary of setting tasks;

$d_{\text{d.MPI}}$ – distance of the MPI location from the protection object;

V_{AAM} – air attack vehicle speed;

$t_{\text{d.p.MPI}}$ – the time of direct preparation of the MPI to neutralize the means of air attack;

$t_{\text{t.n}}$ – time for neutralization of the means of air attack at the border of the zone of neutralization.

In block 3, the calculation of the spatial zone of the possible placement of means of physical influence is carried out. Fragments of the EC should not fall on the object of protection, therefore the disposal of the EC should be carried out on average (depending on the type of EC) at a distance of 2 km or more from the object of protection. Proceeding from this place of placement of anti-aircraft guns, they must move beyond the territory of the protection object at a distance of 1 km or more. The greater the distance of the location of the MPI, the greater the probability of preserving the object of protection. On the other hand, the greater the distance of the location of the MPI from the object of protection, the more means must be involved for its reliable protection. In practice, the number of means that can perform tasks is limited [10]. Therefore, it is necessary to place the locations of means of physical influence as close as possible to the object of protection, guided by their characteristics and the number of MPI allocated for the protection of the object.

After obtaining the value of the required distance of the location of the anti-aircraft fire protection system beyond the protection object, the required number of anti-aircraft fire protection devices is calculated (block 4).

The next step is the implementation of the algorithm for correcting the calculated coordinates of the location of the MPI based on the analysis of the digital map of the area (block 5). If the terrain or the nature of the terrain creates obstacles for the placement of the MPI, then correction of their placement is carried out. A program for displaying the MPI in accordance with the proposed locations on the electronic map is being implemented [10].

For a more detailed and qualitative assessment of the location of the MPI in block 6, an algorithm for assessing the degree of protection of objects by means of physical impact was implemented. The assessment of the degree of protection of objects is performed in the form of a calculation table showing the coefficients of the overlap of the neutralization zones and the load coefficients of the MPI. Using this information (blocks 7-9), the final decision is made regarding the locations of the MPI.

With regard to the location of means of radio-electronic influence, it is appropriate to indicate the definition of such places where they can operate without interfering with the work of the MPI. This is, for example, taking into account the norms of frequency-territorial spread, the appropriate distance between MPI and REI when they work together.

4.2. Determination of the compatibility of the actions of means of physical influence and radio-electronic influence due to the analysis of their compatible actions.

In order to assess the impact of the compatibility of means of physical and radio-electronic influence on the effectiveness of their combined actions, it is necessary to consider the essence of the term "compatibility", as well as to logically connect the concepts and terms related to the concept of "compatibility of physical and radio-electronic influence".

At the same time, the terminological system and its elements-terms must have certain properties that are presented to it:

systemic conditioning of terms, their interdependence, subordination according to a certain feature;

unambiguity within military science and general science disciplines;

context-independent term clarity;

correlation of the term with only one concept;

the brevity of the term and the lexicographic approach to creating terms;

the ability of the terminology to expand, clarify and change, the possibility of the transition of the term to the designation of a generic concept.

Based on the listed requirements for terminology and the analysis of existing basic special terms, the "zone of combined actions of means of physical influence and means of radio-electronic influence" means the territory where they are located and the area of airspace where neutralization and radio-electronic suppression of air attack means is carried out.

Thus, the application of all possibilities related to the use of means in the zone of joint actions should be considered as a set of four constituent parts:

1. "Information interoperability of means of physical influence and radio-electronic influence" – as the ability to carry out coordinated simultaneous actions of these means in the zone of simultaneous duty.

2. "Compatibility with regard to the conditional neutralization of AAM by means of physical and radio-electronic influence" – as the ability to take coordinated actions on PPE in the zone of compatible actions of means of physical and radio-electronic influence.

3. “Electromagnetic compatibility of the effective use of means of physical influence and radio-electronic influence” – as the ability of radio-electronic means to simultaneously function in real operating conditions with the required quality under the influence of unintentional radio interference and not to create unacceptable radio interference to other means [13].

4. “Compatibility for effectively changing the location of means of physical and radio-electronic influence” – as the ability to simultaneously fold, move taking into account the possibility of the means and quickly deploy to a new location.

The evaluation of the effectiveness of the combined actions of MPI and REI is intended to solve the scientific task, achieve the goal of the research and includes:

– selection and justification of indicators of the effectiveness of the use of MPI and REI;

– research on the dependence of the effectiveness of the combined actions of MPI and REI on the formalized indicators of alternative options for the use of MPI.

4.3. Determining the effectiveness of protection of critical objects of the energy complex from air strikes due to the combined use of physical impact and radio-electronic impact means.

In general, the scientific task of researching the combined actions of means of physical and radio-electronic influence in the protection zone of the CFEC is multivariate. The number of options (n_{var}) depends on the number and types of these means and can be determined by the ratio:

$$n_{\text{var}} = (N_{\text{MPI}_i} + 1)(N_{\text{MPI}j} + 1)(N_{\text{n.r.s}} + 1)(N_{\text{r.r.s}} + 1)..., \quad (2)$$

where N_{MPI_i} – the number of means of physical influence of the *i* type;

$N_{\text{MPI}j}$ – the number of means of physical influence of the *j* type;

$N_{\text{n.r.s}}$ – the number of noisy radio interference stations;

$N_{\text{r.r.s}}$ – the number of pulse response radio interference stations.

The composition of means of physical influence and radio-electronic influence and the order of their placement are mutually determined and closely interdependent. This relationship is caused, on the one hand, by those methodological approaches that exist to justify the optimal quantitative composition due to the necessary order of their placement, on the other hand, by the fact that any composition of means must be placed relative to the object of protection in a rational way [9]. The effectiveness of joint actions depends both on the composition of the means and on the order of their placement, the parameters of which are the range of the places of placement of means of physical influence $(d_{\text{l.MPI}})$ and means of radio-electronic influence $(d_{\text{l.REI}})$ from the borders of the object of protection and mutual distances between the means protection $(D_{\text{MPI-REI}})$.

Thus, a rather complex nature of the dependence of the effectiveness of the MPI and REI actions is obtained, which can be represented in the form of a functional dependence:

$$\mathrm{E} = f\left\{N_{\mathrm{MPI}}\right\}\Big|_{N_{\mathrm{REI}},\, d_{\mathrm{l.MPI}},\, d_{\mathrm{l.REI}},\, D_{\mathrm{MPI}_i},\, D_{\mathrm{REI}_i},\, D_{\mathrm{MPI\text{-}REI}} = \text{ const.}} \quad (3)$$

$$\mathrm{E} = f\left\{N_{\mathrm{REI}}\right\}\Big|_{N_{\mathrm{REI}},\, d_{\mathrm{l.MPI}},\, d_{\mathrm{l.REI}},\, D_{\mathrm{MPI}_i},\, D_{\mathrm{REI}_i},\, D_{\mathrm{MPI\text{-}REI}} = \text{ const.}} \quad (4)$$

Places of placement of means are subject to the requirements of the task, i.e. places of placement of means of physical influence must be located at such a distance from the borders of the object of protection that ensures the removal of the neutralization zone of the means abroad from which it is possible to perform tasks of the AAM.

To assess the impact of the maximum effectiveness of the use of MPI and REI on the effectiveness of their combined actions, let's return to the essence of the term “compatibility”.

The evaluation of the effectiveness of the combined actions of means of physical and radio-electronic influence during the protection of critical objects of the energy complex is intended to solve the scientific task, achieve the goal of the research and includes:

– selection and substantiation of indicators of effectiveness of combined actions of means of physical and radio-electronic influence;

– research on the dependence of the effectiveness of the combined actions of means of physical and radio-electronic influence on the formalized indicators of alternative options of different composition of these means.

The indicator of the quality of the result (effectiveness) of actions during the protection of critical objects of the energy complex is, in general, an m-dimensional vector that includes three groups of components: the achieved (expected) effect (g), time consumption (t) and resource consumption (c).

$$Y^m = \left\lfloor g^m, c^m, t^m \right\rfloor, \quad (5)$$

where Y^m – effectiveness of actions;

m – factors and conditions that determine the effectiveness of actions;

g^m – achieved (or expected) beneficial effect;

c^m – expenditure of resources;

t^m – waste of time.

The most adequate target for the purpose of means of physical impact during the protection of objects from air strikes is the indicator of the number of neutralized WPS from their total number that were involved in the strike. As for the selection of indicators of the ratio of opposing forces, the most complete confrontation of the MPI and AAM can reflect the ratio:

$$\sigma_i = \frac{K_{MPI_i neut\ max}\left[1-\left(1-P_{prob.MPI_i neut}\right)^n\right]K_{e.inf.prov}\,N_{MPI_i}}{D_{lim.par.MPI_i zone}\qquad N_{AAM}} = \frac{K_{MPI_i c.p.}K_{e.inf.prov}}{N_{AAM}}, \quad (6)$$

where $K_{MPI_i neut\ max}$ – the maximum number of MPIs of the i type that are simultaneously neutralized;

$P_{prob.MPI_i neut}$ – the probability of neutralization of MPI of the i type;

n – amount of spent resources;

$K_{e.inf.prov}$ – efficiency ratio of information provision;

N_{MPI_i} – the number of MPIs of the i type;

$D_{lim.par.MPI_i zone}$ – the limiting parameter of the MPI neutralization zone of the i type;

N_{AAM} – the number of military personnel involved in the attack on the object of protection;

$K_{MPI_i c.p}$ – coefficient of MPI combat potential of the i type.

$$K_{e.inf.prov} = \frac{K_{coef.f.p}K_{mask}\left(1+N_{\Sigma_{t.p}}\right)N_{\Sigma_{i.m}}}{t_{s.MPI}\left(1-t_{i.c}\right)}, \quad (7)$$

where $K_{coef.f.p}$ – the similarity coefficient of false placements with true ones;

K_{mask} – object masking factor;

$N_{\Sigma_{t.p}}$ – the total number of forces and means of protection of the object of air strikes, which carry out disinformation measures;

$N_{\Sigma_{i.m}}$ – the total number of information means in the composition of forces and means of protecting the object from air strikes, information flows participating in the collection process;

$t_{s.MPI}$ – time of stay of the MPI at the place of placement;

$t_{i.c.}$ – time of information collection.

Thus, the neutralization of AAMs during the protection of CFECs against air strikes is considered as a probabilistic process characterized primarily by the ratio of the forces of the parties.

In turn, to evaluate the effective use of means of radio-electronic influence to protect critical objects, the mathematical expectation of the number of AAM on which radio-electronic influence (suppression) of REI was carried out is used ($M_{AAM\ sup.REI}$).

$$M_{AAM\ sup.REI} = N_{AAM.\ sup}\,\Delta P_{i.p}, \quad (8)$$

where $N_{\text{AAM. sup}}$ – the number of AAM that were subjected to radio-electronic influence (suppression);

$\Delta P_{\text{i.p}}$ – the increase in the probability of saving the object, which is equal to the probability of conditionally neutralization of the AAM, which is determined depending on the number of conditionally neutralized AAM and is calculated according to the following formula:

$$\Delta P_{\text{i.p}} = P^{\text{p}}_{\text{p.rei}} - P^{\text{o}}_{\text{p.a.rei}}, \quad (9)$$

where $P^{\text{p}}_{\text{p.rei}}$ – the probability of preserving the object of protection in the conditions of countering the means of radio-electronic influence (obstructing them);

$P^{\text{o}}_{\text{p.a.rei}}$ – the probability of preserving the object of protection in the absence of countermeasures against means of radio-electronic influence.

For the case of protecting the object only the expression (9) can be transformed into the form:

$$P_{\text{REI}} = 1 - \text{e}^{-N_{\text{REI}}\,\Delta P_{\text{p.s.REI}} / N_{\text{AAM}}}, \quad (10)$$

where $P_{\text{p.s.REI}}$ – the probability of saving a critical object is only REI;

N_{REI} – number of REI;

N_{AAM} – number of AAM.

The analysis of ratios shows that when evaluating the effectiveness of actions, only the capabilities of the MPI or the capabilities of the radio-electronic influence of the REI with a fixed number of AAM participating in the strike on the object of protection are taken into account [7].

Therefore, as a result of the above-mentioned shortcoming, for conducting research it is proposed to convert the dependence into a form that allows determining the efficiency indicator of compatible actions:

$$P_i = 1 - \text{e}^{-\left(\frac{M_{\text{m.e.dest. MPI}}}{N_{\text{AAM}}} + K_{\text{comp.}}\frac{M_{\text{m.e.dest.REI}}}{N_{\text{AAM}}} + K_{\text{o.r.}}\frac{M_{\text{m.e.dest.low.alt}}}{N_{\text{AAM}}}\right)}, \quad (11)$$

where $M_{\text{m.e.dest. MPI}}$ – mathematical expectation of the number of destroyed AAM by MPI;

K_{comp} – compatibility coefficient of MPI and REI;

$M_{\text{m.e.dest.REI}}$ – mathematical expectation of the number of destroyed AAM by REI;

$\text{K}_{\text{o.r}}$ – coefficient of opportunity realization;

$\text{M}_{\text{m.e.dest.low.alt}}$ – mathematical expectation of the number of destroyed AAM at low altitudes.

Therefore, it can be concluded that for the evaluation of the effectiveness of the combined actions of MPI and REI, a generalized indicator was chosen in the form of a

mathematical expectation of the number of AAM who did not complete the task, defined in relative value (P_i) and calculated according to formula (11). Based on the value of this indicator, it is possible to evaluate the expected results of the actions of the MPI and REI, the level of losses of the AAM and the extent to which they fulfill their task of damaging a critical object of the energy complex.

For the placement of means of physical influence on the site, a methodical technique was used for the directed selection of possible variants of the composition of the means within the framework of the existing structure, with the conditional placement of MPI at fixed distances (J) between the means $(\text{MPI} - \text{REI})$ relative to the object of protection.

To implement this technique, we will use the ratio:

$$D_{\text{MPI–REI min}} = \text{a} \cdot J \tag{12}$$

where $D_{\text{MPI–REI min}}$ – the minimum range of MPI and REI from the center of the object of protection, at which their given number is evenly spaced at J intervals;

a – uniformity factor.

For MPI and REI relative to each other and the object of protection, we use the ratio:

$$D_{\text{MPI–REI min}} = D_{\text{det}} \le 0{,}65 D_{\text{r.a}} \ , \tag{13}$$

where D_{det} – detection range;

$D_{\text{r.a}}$ – the minimum range of ammunition.

$$D_{\text{r.a}} = V_{\text{AAM}}\ T_{\text{am.d.AAM min}} - \Delta + V_{\text{AAM}}\ T_{\text{AAM dest}}, \tag{14}$$

where V_{AAM} – speed AAM, km/min;

$T_{\text{am.d.AAM min}}$ – time of ammunition drop using AAM, min;

Δ – lag of weapons (ammunition) using AAM, km;

$T_{\text{AAM dest}}$ – time of AAM destruction.

In order for the object to be protected by means of radio-electronic influence, it is necessary to place REI at a distance D_{REI}, which should be less than $D_{\text{MPI–REI min}}$ and, in the best case, be equal to zero.

However, the reduction of the displacement of REI locations (D_{REI}) is limited by the possibility of destroying the object of protection when using weapons that are self-guided by REI radiation. The condition that determines the minimum and at the same time optimal value of D_{REI} has the following form:

$$D_{\text{REI}} \ge D_{\text{r.d.am}} + d_{\text{r.prot}} + 3\sigma_{\text{a.s.error}}, \tag{15}$$

where $D_{\text{r.d.am}}$ – radius of damage by ammunition to the object of protection;

$d_{\text{r.prot}}$ – the radius of the protection object;

$\sigma_{\text{a.s.error}}$ – average squared error of weapons with homing.

The task of calculating the distance between the locations of anti-aircraft missiles during the protection of the object from air strikes is solved by selecting the locations of anti-aircraft missiles in two stages.

At the first stage, proposals for the placement of means of physical influence are developed in accordance with the requirements of the governing documents and the practice of organizing the protection of critical objects without taking into account the topography of the area [9].

At the second stage, correction of the coordinates of the placement of means of physical influence is carried out, taking into account the relief and nature of the terrain, the location of local objects, which affect the effectiveness of the use of PFV for decontamination of hazardous waste, using the capabilities of digital maps of the area.

The conducted analysis showed that it is necessary to have pre-equipped places for placement of means of physical and radio-electronic influence along the entire zone (perimeter) that is intended for preservation, or in the most important directions.

In each specific case, these factors must be taken into account when building a system to protect objects from air strikes.

The developed proposals were elaborated in a comprehensive model for evaluating the effectiveness of actions of means of physical influence.

The simulation that was carried out made it possible to obtain estimates of the probability of preserving the object of protection in the event of air strikes for typical anti-aircraft missiles, which can be cruise missiles and UAVs at different heights (Fig. 2).

The following flight heights were selected and displayed on the histogram AAM:

1 – up to 100 m;
2 – 100 –500 m;
3 – 500 – 1 000 m;
4 – more 1 000 m.

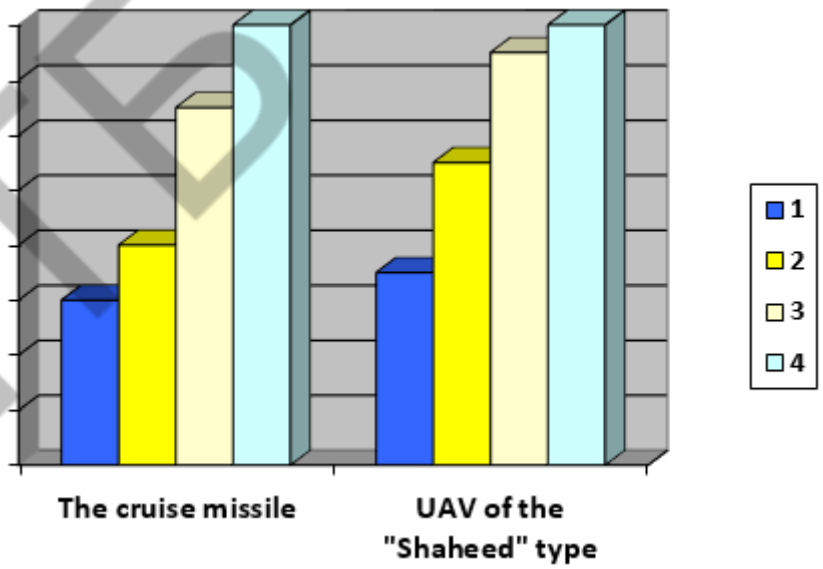

Figure 2. CFEC conservation probability plot

The analysis of the obtained results allows us to conclude that the application of the proposed proposals will allow saving the object of protection in case of air strikes with a probability of 0.7 to 0.8. Therefore, applying these proposals, it is possible to significantly ensure the protection of both the critical object of protection and the

civilian population, as well as the territory from the possible consequences of damage to critical objects of the energy complex.

V. CONCLUSIONS

The list of critical objects of the energy complex for air strikes can be diverse and include important state objects that require reliable protection from air strikes.

According to the presented methodology, placement of means of physical and radio-electronic influence along the perimeter of the object of protection at specified distances allows, in case of neutralization of UAVs and cruise missiles, without causing them to fall into the territory of the CFEC.

The developed proposals for the use of means of physical influence to protect critical objects of the energy complex from air strikes in the integrated model for evaluating the effectiveness of the actions of the MPI allow us to state with confidence that the use of these proposals during the protection of the CFEC from air strikes will make it possible to ensure its security from with a probability ranging from 0.7 to 0.8. To evaluate the effectiveness of the combined actions of the MPI and REI means, a generalized indicator was chosen in the form of a mathematical expectation of the number of AAM that did not complete the combat task, defined in the relative value (P_i). Based on the value of this indicator, it is possible to evaluate the expected results of the actions of the MPI and REI means, the level of losses of the AAM and the degree of their fulfillment of tasks.

Studies show the expediency of taking measures to increase the effectiveness of the protection of the state's CFEC against air strikes due to the joint use of various forces and means, which is due to the need to ensure the vital activity of the state, the preservation of the ecological situation of the region where this or that critical object is located due to catastrophic consequences in the event its damage.

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5. ECOLOGY AND ENVIRONMENTAL PROTECTION

ECOLOGICAL ASSESSMENT OF THE TERRITORIAL COMPLEXES OF TATARBUNARS'KYI DISTRICT OF ODESSA REGION

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Abstract. *A geo-ecological assessment of the Tatarbunar district was carried out on the basis of spatial geo-informational analysis of remote sensing data. The distribution of heating of different types of land in the district and the amplitude of their fluctuations was analyzed based on thermal scanners - TIRS of the Landsat8 satellite. A seasonal analysis of the vegetation cover dynamics was carried out based on the values of the NDVI vegetation index. This is a spatial characteristic of the moisture content of different types of land in the district based on the NDMI index. According to these indicators, it is demonstrated that agricultural arable land has significantly greater heterogeneity than other types of terrestrial land. A comparative analysis of the percentage of the natural reserve fund of the district with other districts of Odesa, Mykolaiv and Kherson regions was carried out. The proposed ecologically balanced territorial structure of the land organization and measures to increase the ecological stability of the agro-landscapes of the district. A detailed hydrologomorphological analysis of the Karachaus estuary was conducted, on the basis of which reclamation and nature protection measures were proposed.*

Keywords: *Tatarbunar district, northwestern Black Sea region, GIS analysis, remote sensing, anthropogenic load, natural and territorial complexes, ecological and economic balance, ecological management.*

I. INTRODUCTION

Tatarbunars'kyi District is located in the southwestern part of Odessa region and reflects the main landscape and economic features of the region: aquatic, agricultural, resort resources, and nature conservation areas. On the other hand, it is a typical District with extensive land plowing, with a dominant anthropogenic influence in the form of agricultural activities which consist of 91% of the total area of agricultural territories that are presented by arable land, while 4.16% of the arable land is degraded [1]. That information alone is enough to come to a conclusion that such land structure and resource management has a complex negative impact on ecological and economic processes, and cannot ensure sustainable development of the region, it is particularly antagonistic to the unique transitional wetland ecosystems of international importance [2], located within the area (degradation of watercourses, siltation, xenobiotic contamination, eutrophication, reduction of biological diversity, etc.)

Earth remote sensing (ERS) data - spectrozonal satellite images, digital terrain models, and geoinformation systems (GIS) - can be involved in addressing the region's balanced environmental management problems, as it provides simultaneous coverage of the whole region under study, regular monitoring and significant reduction of the

cost of expensive expedition work, allowing to obtain a large array of characteristics of the status of territorial complexes of the area. Remote methods are based on the ability of spatial objects to emit, scatter, and absorb electromagnetic waves of varying intensity. The value of environmental indicators based on ERS is found like a function of the amount of reflected or absorbed radiation, which contributes to its remote identification [3].

II. LITERATURE ANALYSIS

Quantitative methods, based on the ratio of natural and anthropogenic elements [4], for estimating anthropogenic changes of landscapes have become the most prevalent for assessing the level of transformability of natural-territorial complexes. Methods of landscape and ecological optimization, as well as estimation of economic and ecological balance of the region based on the inventory of the areas with their ranking according to the degree of anthropogenic changes are presented in the works of O. L. Popova (2012) [5] and L.P. Tsaryk (2009) [6]. An integrated approach to the sustainable management of the usage of administrative territorial units is discussed in the following works [7-13].

Several issues regarding Ukraine's planning of the land-usage structure were addressed with the consideration of international experience, natural and economic features [5, 14, 15].

In the works of the Institute of Plant Physiology and Genetics of the NAS of Ukraine and the Space Research Institute of the NASU-SSAU (including joint ones) methods for assessing the characteristics of terrestrial plant biomass from spectra reflection (spectral signatures) were developed and proposed, issues of satellite data validation using spectrometric field measurements were considered [16-18].

In the monograph of V.I. Lyalko and M.O. Popov the following issues of multispectral space information application for solving nature management problems were considered: establishment of forests' species composition; forecasting of grain yields; determination of the geo-ecological status of natural technogenic systems, etc.; materials, methods, and models of interpretation of Earth remote sensing data for environmental monitoring were outlined [19].

The use of spectroradiometer data, the Landsat and MODIS series of satellites in particular, in the assessment of thermal fields and the moisture content of artificial and natural terrestrial surfaces (territorial complexes) is reviewed in the works [20, 21].

Adaptive-landscape principles of applying field-protecting forest cultivation, including the area of required field-protecting forest areas [23], were reviewed in Odesa region, including Tatarbunars'kyi District.

The environmental status of land resources of the mentioned District has been estimated based on plowing indicators, humic matter content, environmental sustainability, erosion, and others, including integral indices [22]. It is clearly demonstrated that the land resources of the area do not meet the requirements of rational natural use due to, first of all, the violation of the ratio of arable land.

Recommendations for the location of agricultural crops are proposed, and so is the use of ERS data for the quantitative assessment of vegetation of Tatarbunars'kyi District [24]. An assessment of the recreational potential of the administrative regions

of Odesa region by the integral characteristics of the resource, ecological, infrastructural, and consumer factors is carried out in [25], where it is shown that Tatarbunars'kyi District is very promising for studies of ecological tourism, balneology, and recreation at the expense of a large number of objects of nature conservation fund, firth and estuary natural complexes. Structural features of the eco-network, including the objects of the nature conservation fund, their territories and prospects for expansion [2], are also taken into consideration. An analysis of natureprotecting regime of coastal protection lanes (CPL) of Tatarbunars'kyi District's hydro-ecosystems and their structures has been reviewed in [26] and it is noted that the District is characterized by a very little amount of CPLs with corresponding project documentation. In the very same work, there is an analysis of the problems of efficient and integrated use of the Sasyk estuary that was desalinated as a result of river water transmission from the Danube-Sasyk channel. Collective works [4, 27], with a consideration of anthropogenic influence, have analyzed the peculiarities of hydrological, hydro-chemical and hydro-biological regimes of the ecosystems of estuary complexes located within the area, estuaries of the «Tuzlov group» (Shagany, Alibey, Burnas) in particular. The morphometry and toponymy of the water bodies of the «Tuzlovs'kyi estuaries» national park were also discussed in [28]. For these objects, a comparative classification according to morphometric and hydrological characteristics, as well as their natural resistance, has been conducted [29, 30].

Highlighting previously unresolved parts of the general problem. Certain possibilities of using the Earth remote sensing data for functional estimation of the lands that were changed by anthropogenic activities are carried out in this work. First of all, arable land, with an analysis of the ecological and economic balance of the area based on geoecological coefficients, and then emphasis on the areas that are primarily exposed to ecological risks of exogenous processes and the influence of anthropogenic factors based on geomorphological features using digital terrain models. Measures to improve the ecological stability of agro-landscapes and the landscape-anthropogenic structure of the area's lands are proposed. Hydrographic zoning and catchment areas of Tatarbunars'kyi District were conducted. For one of them - the catchment area of the Karachaus estuary, hydrologic-morphological features were analyzed, and an improved scheme for nature management was developed. The presented cartographic material of the aforementioned components, and despite the fact that the materials of the article are primarily demonstrative and methodological, can be used for further, deeper spatiotemporal assessment of the ecological status of territorial complexes of the region, aimed at developing new management plans for sustainable nature usage.

Formulating the purpose of the article. The purpose of the work is: functional assessment of the ecological status of the economic landscape structure, and development of recommendations for protecting natural territorial complexes of Tatarbunars'kyi District in Odesa region based on the use of GIS and ERS data.

The main tasks aimed at achieving the goal were:

- estimation of ecological parameters (temperature of warming of the territorial complexes, aridity, condition of plant-based biomass), and their interrelation in spatial and temporal dynamics simultaneously in the whole District;
- assessment of the state of nature management and its balance;

- terrain analysis and emphasis on the areas that are primarily the most at environmental risk of exogenous processes and influence of anthropogenic factors;

- hydrographic zoning and measure development for sustainable use of nature, for natural conservation of the catchment area of the Karachaus estuary at the «Tuzlovs'kyi Complex».

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The Landsat8 satellite images with OLI and TIRS sensors [31], as well as 30m digital terrain relief models obtained from the international «Shuttle radar topographic mission» (SRTM30), radar image [32] were used as an output. Spatial distribution of the population was carried out on the basis of «OpenStreetMap» data [44], using automatic IDW (inversely-weighted distance) interpolation. Spatial analysis and data processing were performed in QGIS v 3.4.6 software software package with integrated SAGAGIS and GRASSGIS tools, namely: vector and raster data processing, spectral index calculation, morphometric and topographic terrain analysis, hydrographic zoning, density calculation and construction of interpolation surfaces, visualization and design of cartographic materials. Radiometric calibration and atmospheric correction of the Landsat8 satellite images were carried out on the basis of the use of the additional «Semi Automatic Classification Plugin» geo-information module also in QGIS v 3.4.6.

To calculate the spectral brightness of distant infrared radiation in a unit of temperature, the values of the calculated coefficients were used according to the calculation method from the metadata file attached to the satellite images [34].

The Normalized Difference Vegetation Index - NDVI [35-37], which is one of the most common indices for the quantification of vegetation, has been calculated for its main purpose.

The watershed distribution was estimated using the modified Normalized Differential Moisture Index (NDMI), which is derived from the near and short-wave infrared parts of the wavelength spectrum and characterizes the aridity level of landscape complexes [38].

The analysis of land use structure and determination of the anthropogenic load was conducted based on ranking and consolidation of territorial objects into homogeneous groups. The coefficients of anthropogenic transformation of the landscape structure of natural territorial complexes were calculated according to the methodology [5].

LS-factor (length and slope factor) was used to calculate areas with planar erosion potential, which combines the influence of the slope and bevel length of the terrain, calculated according to a corresponding methodology based on the digital terrain model [10].

As a basis for the data of remote sensing of the development of recommendations for the catchment basin of the Karachaus estuary, in addition to the relief data, a Sentinel2B satellite image was used [39].

IV. RESULTS

The spatial distribution of NDVI over time in the area allowed to detect a significant change of the figure within just one month. For example, the calculation of

NDVI on 24.05.2021 has showed that the maximum figures in the range of 0.5-0.81 - dense plant cover (Table 1) had a land area of 341.66 km^2 (Fig. 1), at the end of summer - on 26.08.2021 - lands with maximum index values in the range of 0.5-0.79 occupied an area of 55.45 km^2 (Fig. 2), and a month later plant cover with an index value in the range of more than 0.5 decreased to an area of 13.641 km^2 (Fig. 3), which is 25 times more compared to May, which is primarily related to harvesting and the formation of «bare» land in its place.

A characteristic feature of agricultural landscapes, namely arable land, in comparison with other natural territorial complexes (landscapes) is the presence of significant seasonal dynamics of the amount and density of plant biomass, according to the values of the NDVI index, especially in the May-October period. This feature is associated with the process of treatment and cultivation of this type of land. However, the corresponding values of plant biomass of other types of land during the same period do not change that significantly (Table 2).

Table 1. NDVI index figures for different objects [35]

Type of land cover	NDVI (scale from -1 to 1)	NDVI (scale from: 0 to 255)
Dense vegetation	0.500<=NDVI<=1	210<=NDVI<=255
Sparse vegetation	0.140<=NDVI<0.500	118<=NDVI<210
Poor vegetation	0.090<=NDVI<0.140	105<=NDVI<118
Bare land	0.025<=NDVI<0.090	88<=NDVI<105
Clouds	0.002<=NDVI<0.025	83<=NDVI<88
Snow and ice	-0.046<=NDVI<0.002	70<=NDVI<83
Water	-1<=NDVI<-0.046	0<=NDVI<70

Assessment of the water supply of the territory is an important feature in the field of water management and development of rational water resources usage principles of the region. Spectrozone satellite imaging data, along with field and meteorological studies, provide additional information on soil moisture content and soil cover with the help of, for example, the Normalized Differential Humidity Index (NDMI). High moisture content is inherent in healthy vegetation, which grows faster and is more resistant to fires.

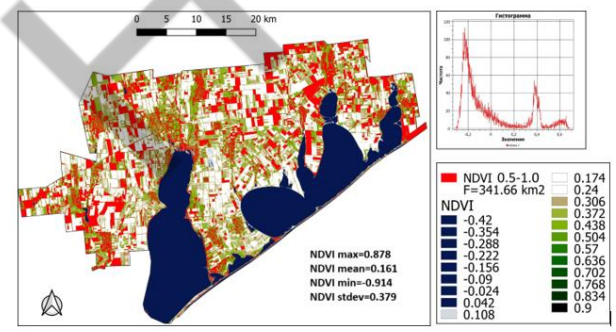


Fig. 1. Distribution of NDVI index on the territory of Tatarbunars'kyi District from 20.07.2021

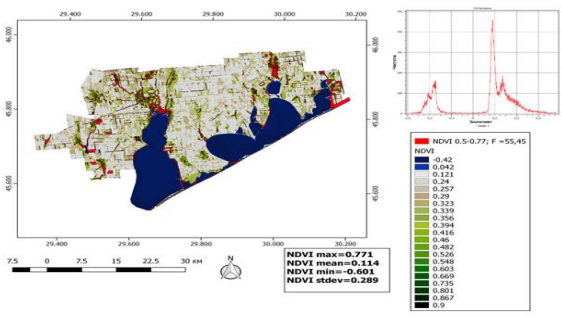


Fig. 2. Distribution of NDVI index on the territory of Tatarbunars'kyi District from 26.08.2021

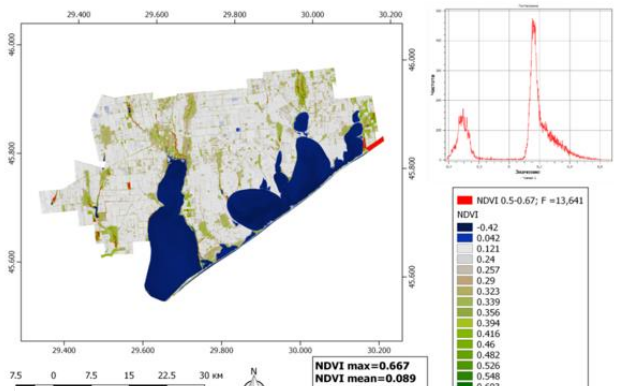
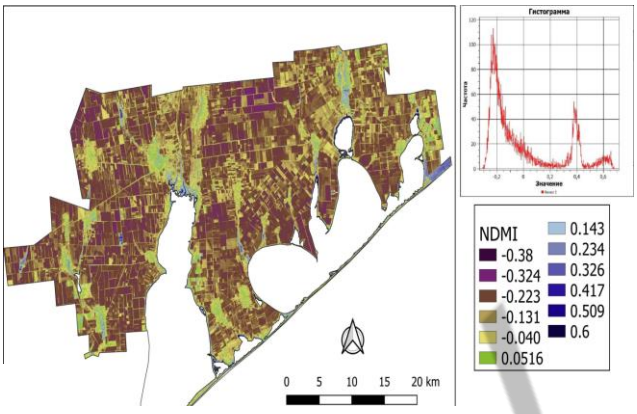


Fig. 3. Distribution of NDVI index on the territory of Tatarbunars'kyi District from 22.09.2021



– Fig. 4. NDMI Index Distribution for Tatarbunars'kyi District from 2021.09.22 according to Landsat8

Table 2. NDVI index figures for Tatarbunars'kyi District

Type of land	24.05.2021			20.07.2021			22.09.2021		
	Mid.	Max.	Min.	Mid.	Max.	Min.	Mid.	Max.	Min.
Arable land	0,57	0,81	0,11	0,51	0,77	0,08	0,14	0,69	0,05
Meadows	0,53	0,79	0,40	0,46	0,70	0,31	0,33	0,56	0,22
Reed beds	0,57	0,81	0,43	0,58	0,79	0,50	0,42	0,62	0,31
Forests	0,75	0,81	0,53	0,74	0,81	0,49	0,55	0,64	0,34

As follows from the distribution of the index on 2021.09.22, its smallest figures are found in plowed soils, the highest figures are found in plant-covered and coastal areas (Fig. 4).

Based on the analysis of the geomorphological features of Tatarbunars'kyi District, which stipulate geochemical flows of terrigenous matter transfer, soil erosion, and other processes, sections with a slope of more than 3º have been highlighted using SRTM30 digital terrain models, which, according to literary data [25], are at the greatest ecological risk of exogenous processes and influence of anthropogenic factors (Fig. 5).

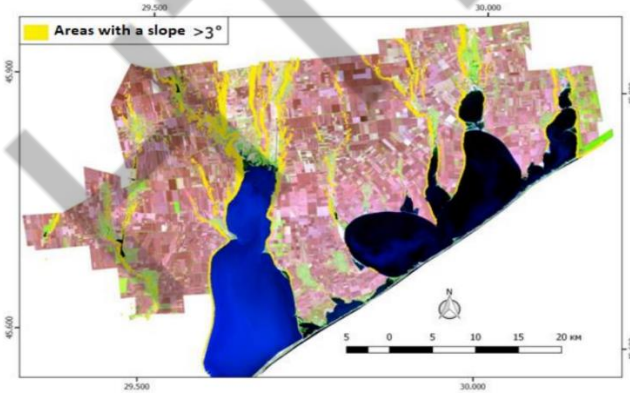


Fig. 5. The distribution of sites with a ≥3º slope on the territory of Tatarbunars'kyi District according to SRTM30 digital terrain models superimposed over a Landsat8 satellite image from 22.09.2021

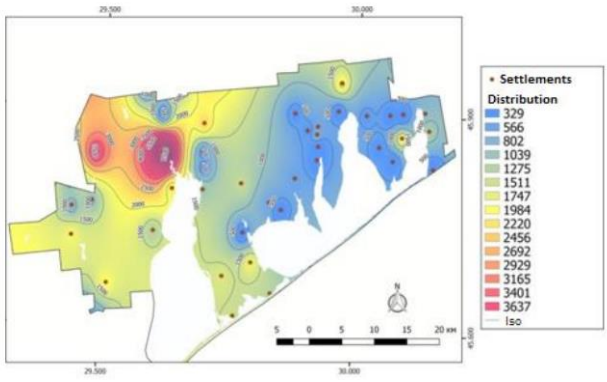


Fig. 6. Population density distribution in Tatarbunars'kyi District, built according to OpenStreetMaps data in the QGIS software package

The location of such sites is inherent in the ridge-girder structures, river valleys and slopes of the estuaries. These areas are recommended to be used in the «natural» state (hayfields, pastures, perennial plantations, recreation and tourism areas) with the removal of arable lands. By their location, almost all of them are part of coastal protection lanes and lands of the water fund in accordance with the Water Code of Ukraine [40], where a full project documentation hasn't been developed yet. From the point of view of ecological and economic balance of the territory, it is most expedient to carry out an inventory of landscape and economic structure, especially in these areas, with their submission to cadastral schemes and land management plans, with the formation of an appropriate environmental regime.

The distribution of settlements and population density in Tatarbunars'kyi District indicates that a large number of them are located precisely on the grounds of river valleys and in places with a slope of more than 3º (Fig. 6), which also leads to intensification of exogenous processes and pollution of water bodies. The aggravating fact is that many of them do not have a centralized sewer system. In general, the territory is characterized by the absence of large cities and low population density.

Another approach to forming a balanced land use structure, ecological network, and sustainable development of the area is hydrographic zoning. According to the requirements of the EU Water Framework Directive [41], which are currently being implemented in national legislation, management of the ecological status of water bodies is based on a basin approach with the development of appropriate management plans and the formation of basin management administration. Small rivers, catchment parts of the Tuzlovs'kyi complex, the Sasik estuary, etc. are located on the District's territories (Fig. 7).

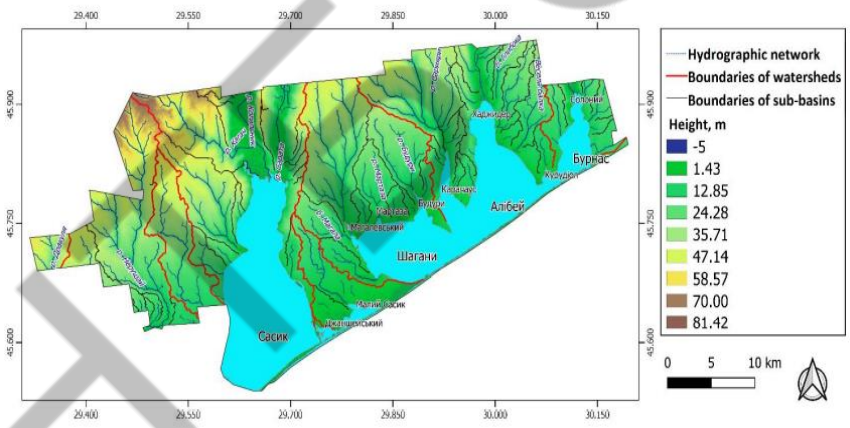


Fig. 7. Hydrographic network of Tatarbunars'kyi District and its watershed boundaries

For further hydrologic morphometric analysis and development of environmental measures, a Karachaus catchment area was selected (a subsidiary estuary with a developed gully-girder system) from the Tuzlovs'kyi complex, within the boundaries of the District. Current capabilities of GIS analysis have made it possible to calculate a number of hydrologically-morphological indicators of the catchment area (Fig. 8), which allow to determine places of the greatest manifestation of exogenous and anthropogenic processes (slope sites, direction and intensity of surface runoff, displays of linear and planar erosion).

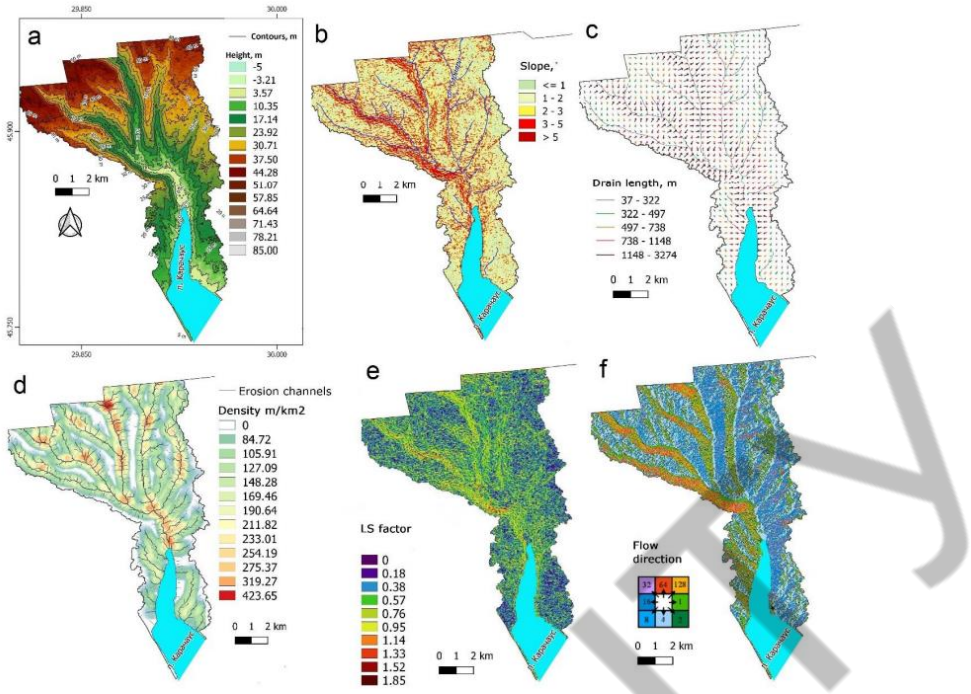


Fig. 8. Hydrologic and morphological features of part of the catchment area of the Tuzlovs'kyi estuary complex within the borders of Tatarbunars'kyi District: a - terrain heights; b - biases; c - flow vectors; d - linear erosion structures and density; e - the risk of plane erosion; f - the drain direction of each raster cell

As evidenced by careful hydrologic morphological analysis, this area does not imply widespre intensive use of nature, as it has a developed gullygirder system and terrain fragmentation. It is clear that environmental management in such conditions must be differentiated in spatial, intensity-based, landscape and settlement-balanced terms, taking the functions of the ecological network into account. Moving on to the proposed sustainable environmental management measures for the further development of an ecological management plan, one should also mention the legally stipulated environmental measures for the water fund lands, and their introduction into nature, especially the nature protection lanes (NPLs) along the watercourses. The principles of their establishment, structure and nature protection regime are determined in accordance with the law of direct action in this field - Water Code of Ukraine (Articles 88-90), which includes NPLs along watercourses, NPLs along seas and estuaries (with beach area allocations) [40].

At present, nature management in the form of ubiquitous plowing of land, unauthorized rural settlement development on the territory of the catchment area is conducted without taking terrain and gully-girder structure into account, without observing agro-technical land protection norms, resulting in both deep and planar erosion (Fig. 9 a), in addition to that, windbreaks are not enough to protect against wind (deflation), and water erosion of soils, as well as the associated reduction of the ecological status of water bodies. Given the hydrological and morphological conditions, state of the lands, regulation of watercourses and environmental legislation, it is proposed to reorient the structure of land use, to increase the number of environmental protection areas, to allocate sites with extensive form of land use, which is certainly going to be ecologically beneficial (Fig. 9 b).

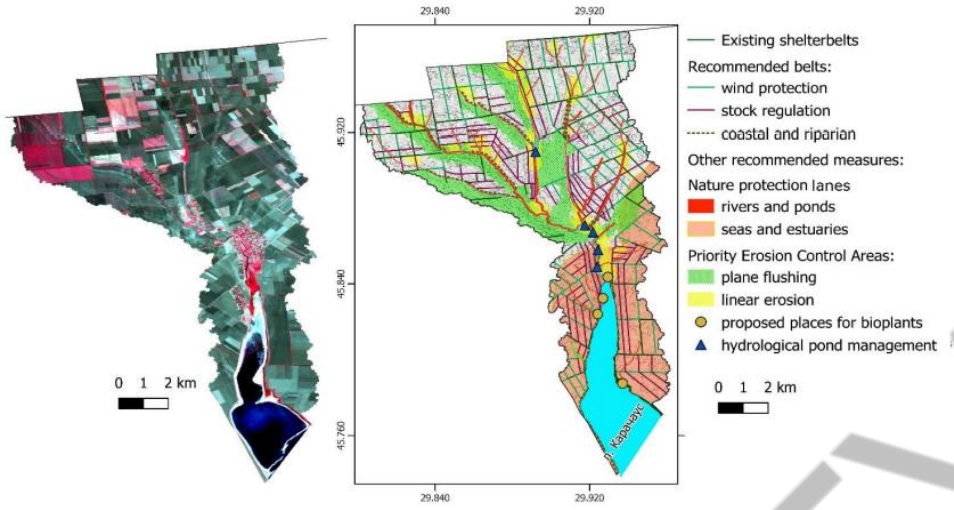


Fig. 9. The existing and recommended structure of land use of the Karachaus catchment area within the boundaries of Tatarbunars'kyi District: a - full-color satellite Sentinel2B image from 2021.09.15 from the combination of NIR-Green-Blue channels (vegetation is red); b - a scheme of reclamation and environmental measures (management plan at its first approximation) [39]

First of all, it is necessary to transfer the water fund lands to the «nature» of applying them to land management plans of settlements and land cadasters. Furthermore, proper agro-technical measures were not met throughout the whole District, among other things agricultural territories are insufficiently countered by protective windbreaks. The existing structure of windbreaks consists of 80.9 km, about one third of the fields do not have any windbreaks at all, the distance between the windbreaks is 1 km on average, the corresponding edging area - 200 ha. This windbreak structure does not fulfill its environmental function, so it is recommended to increase it by 3 times. At the same time it should at least include additional wind protection (92.1 km), stock regulation (124.7 km), coastal and riparian (30.8 km). Additional windbreaks were plotted as follows: windproof, taking into account prevailing wind directions with a cell size of 500 per 1000 m; stock regulation windbreaks were placed on slope sections along the horizontal lines at a distance of 400 - 300 m, depending on the slope; coastal and riparian windbreaks along eroded girders 3 - 5 m from the shorelines. As a prevention of land erosion spread, it is also recommended that some of them (on the slopes of gully-girder systems) carry out sedimentation, conservation, and exploitative reorientation (use in a quasi-natural state - perennial crops, pastures, hayfields, etc.). In order to control the quality and colmatage (mudding) of the organized runoff of ravines and girders, it is proposed to create biological filters in their mouths along the estuary - biological plateaus (artificial ecosystems with sinusoidal filtration biocenoses). Small local rivers from the basin were basically destroyed as a result of a rupture of the hydrographic network and pond overregulation.

It is recommended to either completely eliminate unauthorized ponds, or to allow their operation solely in case of proper environmental documentation and operating modes depending on the water content of the year. It is advisable to use arable land on planar grounds and based on the principles of adaptive agriculture, with the introduction of soil protective crop rotations and the use of unconventional

agrotechnical measures (minimization of soil cultivation, optimization of rotation, improved irrigation systems etc.).

V. CONCLUSIONS

The results of GIS thermal channels analysis of Landsat8 satellite images revealed a significant amplitude of temperature fluctuations of Tatarbunars'kyi District's territorial complexes. The warming of plowed soil is higher by 10 °C than under plant cover in the summer period, which certainly influences the hydrological, geochemical and biological processes of the area at the current level of agricultural development of arable land.

The distribution of vegetation dynamics by NDVI across the area revealed a significant value change seasonally and even within one month. Territories with the maximum index values corresponding with the dense vegetation cover occupied an area of 341.66 km^2 on May 24, 2021, at the end of summer - August 26, 2021, - 55.45 km^2 respectively, and a month later the area of vegetation in this index range decreased to 13.64 km^2 , which is more by 25 times compared to May, primarily due to harvesting and tillage in the form of arable land.

The calculation results of the complex geoecological indicators also showed ecological imbalance of the lands' structure. Irrational farming has led to degradation of the hydrographic network of small rivers in the area, formation of soil erosion, trenching, reduction of the ecological status of water bodies, including nature protection areas with an international status of Ramsar lands.

The distribution of settlements and population in Tatarbunars'kyi District indicates that a large number of them are located on the grounds of river valleys and in places with a slope of more than 3º, which also leads to intensification of exogenous processes and pollution of water bodies.

Management plan of the Karachaus estuary (its first approximation), which is developed on the basis of a hydrologic morphological analysis of the catchment area and land use structure, includes the application of natural protection lanes to the settlements' land management plans and land cadasters, conducting appropriate agro-technical measures, particularly increasing the length of the windbreak system by 3 times with their respective functional purpose. As a prevention of land erosion spread, it is also recommended that some of them (ones on the slopes of gully-girder systems) carry out sedimentation, conservation and operational reorientation (use in a quasi-natural state - perennial crops, pastures, hayfields, etc.). For the possibility of quality control and mudding of the organized runoff, it is proposed to create biological filters (bio-plateaus) in the mouths along the estuary. It is recommended to either complete eliminate unauthorized ponds, or to operate them solely in case of proper environmental documentation and operating modes depending on the water content of the year. Placement and use of arable land is proposed to be based on the principles of adaptive agriculture.

The result of the GIS assessment is geoinformation databases in the form of raster and vector layers that can be used by executives and other stakeholders for further development of the sustainable development strategy of Tatarbunars'kyi area.

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BIOPLATEAU AS A SYSTEM FOR IMPROVING THE WATER QUALITY OF SAYRAN LAKE

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Abstract. *Sairan Lake is a recreational reservoir artificially created in the center of Almaty on the site of a former sand and gravel quarry. The Bolshaya Almatinka River fills the lake. The flow of the Bolshaya Almatinka River is seasonal. In the cold season, water is drained from the reservoir.*

Currently, there is a strong anthropogenic degradation of the recreational potential of Lake Sairan in Almaty. The lake has lost the ability to self-cleanse, at the same time, with the waters of the Bolshaya Almatinka River, an increasing amount of various pollution flows into the lake. The data of the presented studies are the starting part of the project to create an artificial bioplateau on Lake Sairan in Almaty.

The work accepts the hypothesis of restoring recreational quality through the creation of an artificial bioplateau [1], it is related to the fact that the bioplateau will allow the processing of pollutants dissolved in water. Classical water purification methods that use mechanical, physical and chemical methods are characterized by high capital intensity and high operating costs.

The considered provisions make it possible to consider the project of creating an artificial bioplateau on Lake Sairan in Almaty city as economically and environmentally more efficient in comparison with other technologies. This project will provide the necessary recreational water requirements for Lake Sairan. The project should also provide for seasonal cleaning in the bed of the Bolshaya Almatinka River.

Keywords: *Sairan Lake, Bolshaya Almatinka River, recreational reservoir, bioplateau.*

I. INTRODUCTION

Water objects on the territory of large cities should be aesthetically attractive to residents and contain the maximum possible number of recreational services, therefore all types of work aimed at ensuring these principles are of sufficient relevance.

The goal of the work:substantiation of engineering and environmental measures that will allow creating and permanently maintaining the natural-artificial recreational complex of Lake Sayran on the Bolshaya Almatynka River.

Job tasks:

- justification of the relevance of the work and the choice of research methods;
- assessment of the current state of the Bolshaya Almatynka River and Sayran Lake;
- justification of cleaning technology based on natural biological methods;

- substantiation of hydrotechnical structures that provide seasonal supply of water from the Bolshaya Almatynka River for cleaning;

- substantiation of facilities that seasonally provide water purification of the Bolshaya Almatynka River and Lake Sayran to the third quality class.

Scientific novelty: water purification of the Bolshaya Almatynka River and Lake Sayran only during the bathing season, which will eliminate the possibility of destruction of hydrotechnical structures due to possible changes in the regime of the river with a mountainous drainage area.

The work involves the construction of two dams that allow water to be directed to the bioplateau only during the bathing season, the rest of the time the bioplateau will exist only as artificial and natural aesthetic objects.

Practical meaning: the results of the work can be used in the development of engineering and ecological projects for the creation of recreation zones in the city of Almaty.

II. LITERATURE ANALYSIS

Biological treatment of polluted natural and wastewater is based on the ability of various groups of microorganisms to destroy soluble organic substances contained in wastewater in the process of their vital activity, that is, to use dissolved organic pollution of wastewater as food products, as a result of which they receive energy for their vital activities. and wastewater is freed from these pollutants.

Biological cleaning can be carried out by the following methods:

• in conditions close to natural;

• in artificially created conditions.

Biological purification in conditions close to natural ones consists in adapting natural biocenoses of soils or water bodies to receiving wastewater and natural biological oxidation of organic substances contained in wastewater using technical means.

Facilities for the biological treatment of wastewater under conditions close to natural ones are divided into facilities in which treated wastewater is filtered through a layer of soil (filtration fields and irrigation fields) and facilities that are reservoirs (bioponds) filled with treated sewage water In buildings of the first type, the supply of oxygen occurs mainly due to its direct absorption by microorganisms from the air. In buildings of the second type, the supply of oxygen occurs mainly due to reaeration or artificial aeration. However, the low intensity of natural biochemical processes, the large area of buildings and climatic conditions limit the wide application of biological wastewater treatment methods in conditions close to natural ones.

1.1 Biological ponds

Biological pond – a natural or artificially created water object, intended for biological purification (re-treatment) of wastewater, based on the processes of self-purification of water bodies [2]. Biological reservoirs differ from natural reservoirs, where all biological processes occur spontaneously, in that all processes in them are regulated and directed by humans in the direction they need [3].

Biological reservoirs have a small depth - 0.5... 3 m; the area of an individual pond is 0.01... 50 ha. The presence of a significant water-air contact surface ensures heating of the entire water column and its mixing. This creates favorable conditions for the development of aquatic organisms that assimilate biogenic elements and enrich the water with oxygen necessary for the oxidation of organic substances.

Oxidation processes in bioponds are most effective in the warm season. When the water temperature is below 6°C, the intensity of cleaning slows down sharply, and when the temperature drops further, it is almost completely stopped. Therefore, in the winter period, after the formation of an ice cover, when oxygen does not penetrate into the water, only the wastewater in the reservoir freezes. At the same time, in flowing, non-aerated bioponds with higher aquatic vegetation, year-round purification of wastewater from a number of pollutants, in particular from SPAR and oil products, is possible [4-6].

Being the final link in the processes of sewage treatment, biological reservoirs ultimately shape the quality of water discharged into water bodies - rivers, lakes, reservoirs. Most often, bioponds are used as an independent construction for wastewater treatment [7].

Unlike artificial biological treatment facilities, biological ponds, in addition to cleaning from mineral substances and suspended particles, provide a high level of bacterial self-cleaning. In particular, the number of Escherichia coli in bioponds is reduced by 95.9 - 99.9% of the initial content, and helminth eggs in water that has passed through biological ponds are practically absent. Bioponds often include autonomous consumers with a small water consumption in water treatment systems. This makes it possible to combine actual water treatment and aquaculture, as well as partially pay off the costs of building and operating bioponds, making water treatment cheaper in general [8]. Biological ponds are not without disadvantages, the most important of which are the seasonality of work and low oxidation capacity, as well as the need for large areas. At the same time, in addition to their direct functions - sewage treatment, biological ponds can be a source of water for irrigation, serve as breeding of waterfowl and fish.

Biological ponds can be of natural or artificial origin. The former include natural reservoirs and wetlands (swampy areas with a slow water flow on the way to larger reservoirs), the latter include reservoirs specially created by man.

According to the nature of placement, biological ponds belong to three types [9]:

- *rigging and beam ponds* – located in basins blocked by a dam; have the shape of an elongated triangle with the base near the dam;
- *bulk rates* – located in natural recesses; lake-shaped, length and width are approximately the same;
- *dug ponds* – location is arbitrary; the configuration and dimensions depend on the shape and parameters of the excavated pit.

Based on the concentration of effluents discharged into the reservoir, the following are distinguished:

- *biological ponds with breeding* (fish hatchery) – effluents, after preliminary clarification in settling tanks, are mixed with clean river water and sent to single-stage flow ponds of 0.5-7 hectares in size. The duration of water stay in them is 8-12 days;

- *biological ponds without breeding* (multi-stage or serial) - effluents, after preliminary settling, are sent to the pond without dilution with clean water. Ponds without breeding are arranged in 4-5 stages (the area of individual ponds of each stage is 2-2.5 hectares), which water passes through sequentially. The level of water purity gradually increases with each subsequent level. Duration of stay of water - up to 30 days;
- *biological ponds for further purification*sewage - have 2-3 (inflow of treated sewage) or 4-5 degrees (inflow of settled sewage). They are used when there is a need for increased quality of wastewater treatment and their additional treatment after artificial treatment facilities.

There are ponds with natural and artificial aeration, which accelerates water purification processes. The depth of ponds with natural surface aeration, as a rule, does not exceed 1.5 m. Artificial aeration with the help of mechanical aerators or by blowing air through the water column allows you to increase the depth of the pond to 3 m.

According to the presence of the discharge of purified water on the terrain or into water bodies, sewage-free and sewage biological reservoirs are distinguished. According to the method of operation, bioponds are divided into accumulative, contact, flow-through, and filtration-evaporation reservoirs. According to the discharge load on the surface area, biological ponds are divided into low loading (BOD_5 up to 50 kg/ha per day.), with normal loading (BOD_5 from 50 to 150 kg/ha per day.) and high loading (BOD5 over 180 kg/ha per day).

The following types of bioponds are known:

and)aerobic-anaerobic for biochemical treatment of wastewater contaminated with organic impurities and production of biogas (Fig. 1)

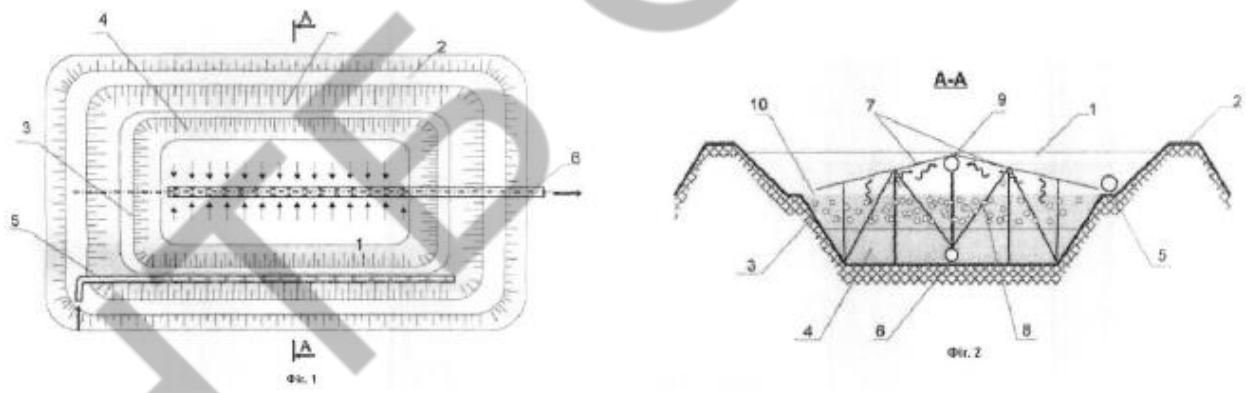
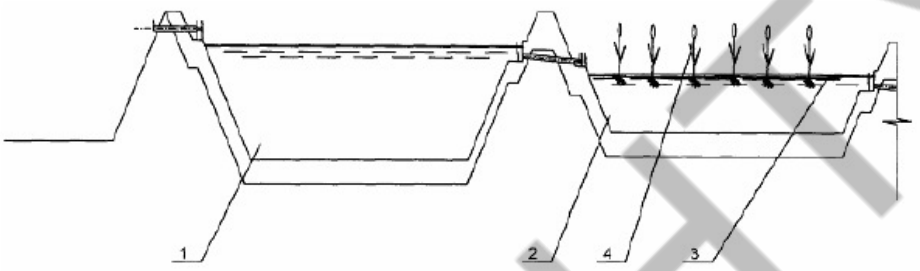


Fig. 1. Aerobic-anaerobic biopond for biochemical treatment of wastewater contaminated with organic impurities and production of biogas

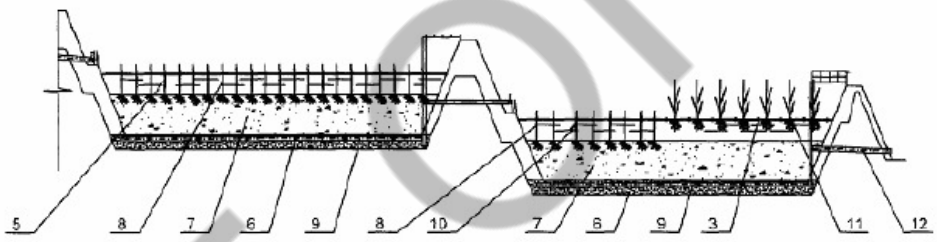
Aerobic-anaerobic biopond for biochemical treatment of wastewater contaminated with organic impurities and production of biogas, in which organic substances in suspension are destroyed by bacteria in both aerobic and anaerobic conditions and further settle and decompose at the bottom in the anaerobic zone, releasing inorganic substances and compounds in the form of biogas, which is characterized by the fact that the lower part of the biopond is recessed for the formation of an anaerobic zone and is covered with a film coating on top, which is located on supports, while a pipeline is laid in the anaerobic zone for the collection and removal of biogas [10].

b) a facility for wastewater treatment using higher aquatic plants (Fig.2)

A facility for wastewater treatment using higher aquatic plants, consisting of serially interconnected bioponds in which sections of higher aquatic plants are kept afloat, which is distinguished by the fact that the facility additionally has a biopond for primary settling of wastewater, between bioponds with a biopond with an area of higher aquatic plants planted on a bioplateau, consisting of a layer of sand and a layer of crushed stone, and the last biopond has an area of higher aquatic plants afloat and an area of plants planted on a bioplateau, and in a biopond placed after a biopond for the primary settling of wastewater, a section of broad-leaved cattail is kept on a float, in the next and last bioponds, lake mullein is planted on the bioplateau,and a section of marsh sedge is kept afloat in the last biopond [11].



Фіг.1



Фіг.2

Fig. 2. A facility for wastewater treatment using higher aquatic plants

Contaminated wastewater enters biopond 1, where organic substances undergo coagulation under anaerobic conditions and settle to the bottom of biopond 1 in the form of flocs. After settling, the water flows by gravity from biopond 1 to biopond 2, where it passes through the root system of broad-leaved cattail 4, stems which are placed on biofence 3 and are not immersed in water. The branched root system of broad-leaved cattail 4 absorbs micro- and macroelements from the water washing it, and the formed biofilm on the roots and rhizomes oxidizes organic substances dissolved in water with the help of atomic oxygen, which is released by the plant through the root stomata.

In addition, in this biopond 2, the remains of suspended substances fall out and oxidation of organic substances takes place due to the saturation of water with oxygen and carbon, which was formed in biopond 1 in the process of anaerobic fermentation of pollutants that settled at the bottom of biopond 1. From biopond 2, water enters biopond 5 , passes through the root system of the lake reed 6 and the loading zone 7, which consists of crushed stone, on which a fouling biofilm is also formed and it practically performs the functions of an additional biological filter. Next, the water

flows into biopond 8, in which the first half undergoes processes similar to those in biopond 5. In the second half of biopond 8, on biofence 3, marsh eider 11 is placed. Placing the marsh sedge 11 at the final stage of wastewater treatment makes it possible to disinfect the purified water from microorganisms and viruses and eliminate the allelopathic effect of the vegetation products of the sedge sedge 11 on the association of the lake sedge 8. The purified water is discharged through the collector 12 into a natural reservoir without chlorination. Larvae and eggs of helminths partially settle in bioponds 1, 2, and in bioponds 5 and 10 they are completely retained on the biofilm of crushed stone fouling 7. Passing water from top to bottom in bioponds 5 and 10 prevents leaching of loading from the ponds and forms an additional degree of purification in the formed biofilter on rubble 7 [11].

1.2. Bioplateau

Bioplateau is a man-made sewage treatment system that resembles bioponds. It is located in a cascade, and is built taking into account chemical and biological methods of cleaning.

If we classify the bioplateau from the point of view of engineering design, and at the same time take into account the hydraulic distribution of water flows, we will get the following categories:

a) superficial;

b) horizontal infiltration;

c) vertical infiltration;

d) bioplateau of mixed type [12].

Each type has its own characteristics and can clean different categories of wastewater.

*Surface bioplats.*The surface bioplate is similar to a "wetland landscape" created by nature, when the runoff is directed to the surface of the structure [13]. The difference from a natural sewage treatment plant is that the bioplateau has management systems that achieve high efficiency in wastewater treatment. Surface bioplats have the following advantages:

- small financial costs for the construction of the purifier;
- ease of management and low energy consumption.

But bioplateau also has disadvantages, namely:

- it is necessary to have large areas for the construction of the system;
- small hydraulic load, therefore - insufficiently high efficiency of wastewater treatment.

Oxygen is supplied to the surface biofields due to diffuse processes (through the root systems of plants). But this method of supplying oxygen cannot fully provide them with the needs of the bioplateau. In addition, the quality of wastewater treatment is affected by climate change. In the summer period, it is necessary to carry out sanitary measures to destroy mosquitoes.

Horizontal infiltration bioplateau. Such bioplateau are called horizontal because the effluents in the device move through the loading layers almost horizontally. The entire device consists of one or more sections. The sections have a waterproof coating, loading layers, and live plants and microorganisms [13].

Advantages of horizontal infiltration bioplates:

- high hydraulic loads are created in them;
- high efficiency of wastewater treatment for BOD and COD, suspended substances, as well as heavy metals;
- absence of an unpleasant smell on the territory of the bioplateau;
- absence of insects.

There is only one disadvantage of horizontal infiltration bioplateau - they remove nitrogen from sewage worse than vertical infiltration bioplateau.

Bioplates of the horizontal type are widely used in European countries, as well as in the USA, Australia and Japan.

Vertical infiltration bioplateau. In a bioplateau of a vertical type, runoff from the surface of the bioplateau falls vertically to the bottom. This structure is supplied with oxygen due to the diffusion of air from the atmosphere, as well as through the root systems of plants. Nitrification processes occur more intensively in vertical infiltration bioplateau than in horizontal ones. Therefore, it is better to use a vertical type bioplateau for cleaning sewage with a high level of nitrogen content [13].

Among the disadvantages of this wastewater treatment system, one should note the difficulty in managing the treatment process, as well as in the process of creating and maintaining favorable conditions for normal operation.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

Object of study– the hydrological complex of the Bolshaya Almatynka River and Sayran Lake.

Subject of study – recreational properties of Lake Sayran.

Lake Sayran is an artificially created reservoir for recreational purposes in the center of the city of Almaty on the site of a former quarry for the extraction of sand and gravel materials. The lake is filled by the Bolshaya Almatynka River, which is formed by the confluence of three water streams of the frontal moraine of two powerful Zailiysky Alatau glaciers. The river is prone to mudslides, destructive mudslides sometimes pass along it, reaching the territory of the city. Today, the riverbed is reinforced and concreted, special concrete barriers are installed along the riverbed, which dampen the speed of water movement during the melting of mountain snow and ice. The area of the lake is 50 hectares, its maximum depth is 12-15 m. In the 1970s, the lake was a popular recreational facility for city residents due to the high quality of mountain water.

In 2022, an excess of the LCP indicator was found in Lake Sairan, which indicates fecal pollution caused by the discharge of untreated wastewater from domestic and industrial enterprises into the river, uncontrolled water pollution by household waste.

To date, there is a strong degradation of the recreational potential of Lake Sayran and the recreation area of the townspeople adjacent to it.

Research methods. The work used general scientific (analysis and synthesis) and special research methods. The theoretical and methodological basis of the research is a systematic approach.

When studying individual issues, the following methods were used: at the stage

of collecting, systematizing and processing information for conducting research - inductive, observation; in the process of theoretical understanding of the problem - deductive and graphical representation of data, as well as methods of analysis and synthesis to combine various components of environmental and economic phenomena in a single process; at the proposal development stage – modeling, grouping, generalization and comparison.

In our work, we used the hypothesis of the possibility of seasonal restoration of the recreational quality of Lake Sayran when using the bioplateau technology. Seasonal cleaning on the bioplateau will eliminate the possibility of consequences from possible emergency situations related to the mountainous origin of the Bolshaya Almatynka River. It should be noted that even a non-working bioplat will have greater aesthetic appeal for city residents.

IV. RESULTS

The ability of higher aquatic plants to purify water has been known for a long time and residentsancient settlements tried to take drinking water from rivers in areas located below massifs of thickets of aquatic vegetation.

Analyzing the biotic component of the river ecosystem, it can be seen that thickets of higher aquatic vegetation develop along the banks of the river, mainly in the places of beam exits, behind which the polluted surface runoff from the catchment area flows into the river. In ponds, lakes and reservoirs, higher aquatic vegetation develops intensively in the most polluted areas of the water body.

This is due to the fact that wastewater from settlements, surface runoff for the development of territories contain organic substances, nitrogen and phosphorus, which are nutrients for plants. Biogenic elements are used by higher algae for their growth and development, and organic substances are subject to bacterial destruction by the periphyton film that develops on the underwater part of plants.

Phytotechnology is a method of cleaning polluted natural and wastewater, based on the use of processes of natural self-cleaning of water bodies, using higher aquatic vegetation, aquatic microflora and microorganisms, which has become widespread in the countries of Western Europe (Great Britain, Denmark, Switzerland, Finland, Spain, France, Germany, Norway, Austria, Estonia), as well as in America, Canada, New Zealand.

The use of phytotechnology is most suitable for the treatment of household wastewater in small settlements, detached houses, schools, sanatoriums, camping sites and other places of public recreation. Phytotechnologies can also be used for the treatment of surface runoff from agricultural lands, built-up areas and industrial sites, collector drainage, quarry and mine waters, wastewater from animal husbandry complexes, leachate from landfills of solid household waste, in the treatment of industrial wastewater and its mixture with household wastewater with water, phytotechnology is used as additional purification.

Such engineering structures as the bioplateau are the most advanced methods of natural biological wastewater treatment, which are widely used in the world [14].

Bioplateau– an efficient, ecological and economic construction for the treatment of various categories of wastewater. The main idea of the technology is to use natural

elements of river protection against pollution and water purification, which use solar energy for their operation and do not require maintenance. These elements primarily include higher aquatic vegetation: reeds, reeds, sedges, reeds, rushes, and many others.

The idea of using higher aquatic plants for wastewater and natural water purification by creating stationary and floating devices was first put forward in Ukraine by the author together with Professor, Doctor of Biological Sciences O.P. Oksiyuk in 1977 [15] and the facilities implementing them were called "bioplateau".

The term "phytotechnology" was proposed and substantiated by UNEP to define similar technological solutions based on the principle of using higher aquatic plants [16].

The main idea of phytotechnology facilities is to filter wastewater through thickets of higher aquatic plants and a specially selected sand-gravel filter with preliminary sedimentation of suspended particles in a sedimentation tank.

The two types of structures differ fundamentally, the schemes of which are shown on Fig. 3.

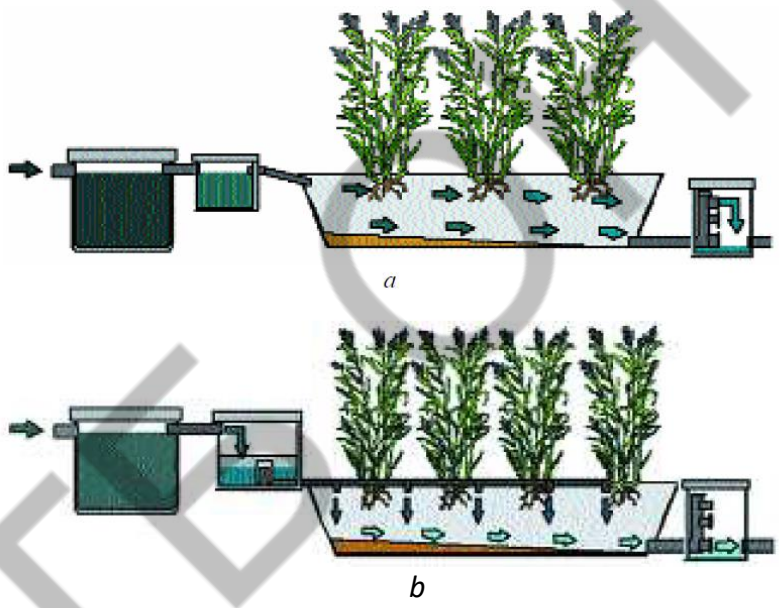
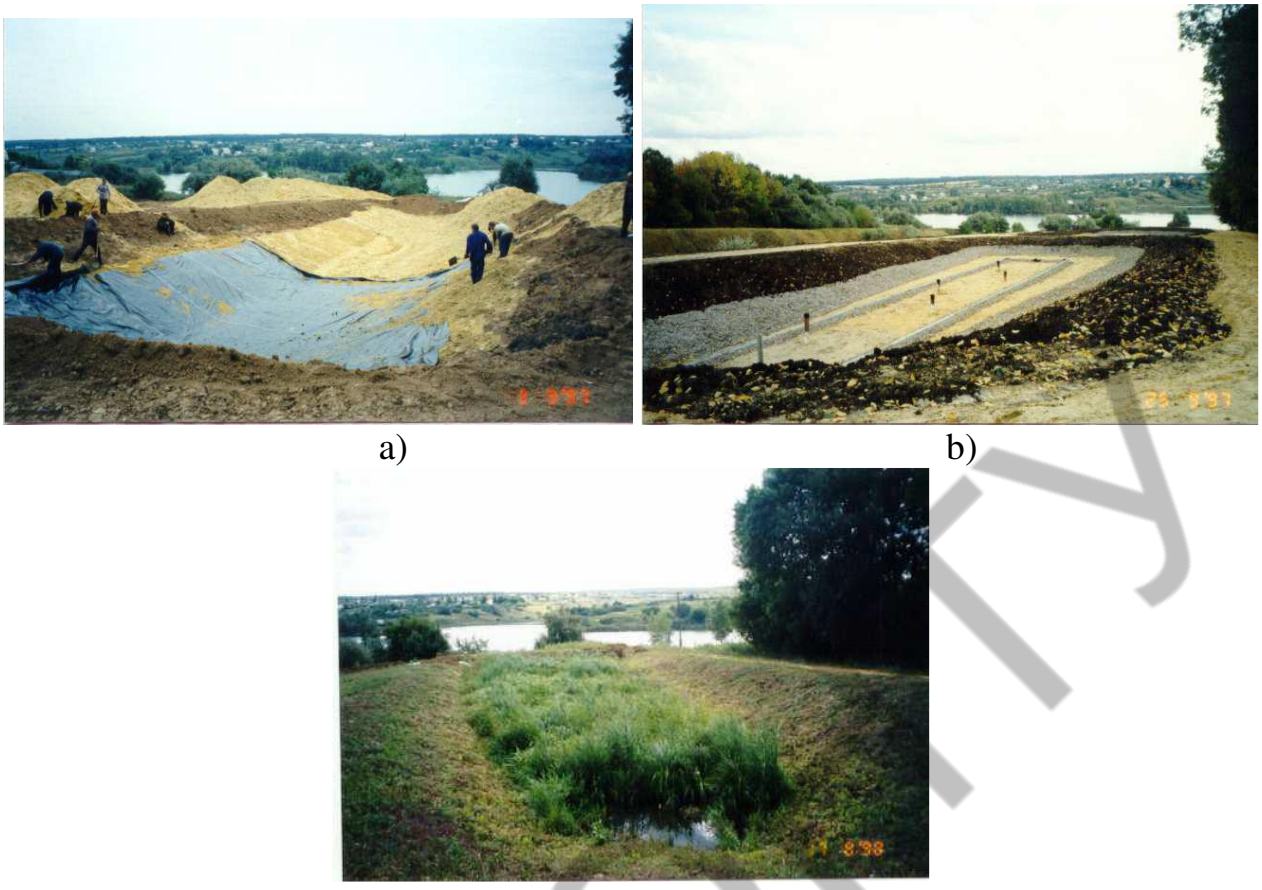


Fig. 3. Schematic diagram of phytotechnology facilities:
a – with horizontal filtering; b - with vertical filtering

The construction of phytotechnology structures is extremely simple, is carried out from local materials and does not require either qualified labor, special mechanisms, expensive materials and devices.

Below are the main stages of the construction of a bioplateau: creating a pit, pouring a sand cushion under an anti-filtration film and laying it to protect groundwater from sewage pollution (Fig. 4, a), the formation of a sand-gravel filter with a wastewater distribution system (Fig. 4, b) and planting higher aquatic vegetation (Fig. 4, c).



a) b)

c)

Fig. 4. Construction stages of the phytotechnology facility in the village of Velyki Prokhody in the Kharkiv region

The type of higher aquatic vegetation that dominates in this area is usually used. Planting is carried out with the help of a rhizome-soil mass, which is excavated by a mechanized method on the coastal areas of the adjacent water body, transported to the place of laying and distributed on the prepared surface of the structure being created.

The system of phytotechnology structures was successfully applied in Ukraine for de-eutrophication of water coming from the Dniprodzerzhyn reservoir on the Dnipro-Donbas canal to Donetsk and Kharkiv. Anti-plankton protection of the main water intake of the canal and a system of coastal and channel bioplateau on the water transportation route were used here [17].

A high purification capacity of phytotechnology facilities has been established, which is not inferior in its efficiency to expensive traditional treatment facilities [14].

Numerous long-term field observations at existing facilities (bioplateau) in different countries established [14] that the efficiency of wastewater treatment according to the following water quality indicators is:

- Suspended substances - 90-95%;
- Organic substances according to BOD content - 95-98%;
- Nitrogen and phosphorus - 50-70%;
- Bacteriological contamination - 99-99.5%.

As you can see, a sufficiently high level of wastewater treatment has been established by various studies of existing facilities. At the same time, the oxygen content increases significantly due to photosynthetic aeration of water.

The technology of wastewater treatment using bioplates has certain advantages and disadvantages compared to traditional municipal wastewater treatment facilities.

The main disadvantage of phytotechnologies is the need for large areas compared to mechanical and chemical-biological treatment facilities, which are usually located on small sites. Therefore, phytotechnology facilities are recommended for pollution sources located in rural areas, where the necessary territorial opportunities usually exist.

The main advantages of phytotechnology are low cost, no need for electricity, ease of construction, and practically no need to maintain operating personnel.

Aquatic plants in reservoirs perform the following main functions:

- filtration (contribute to sedimentation of suspended substances);
- absorptive (absorption of biogenic elements and some organic substances);
- accumulative (the ability to accumulate some metals and organic substances that are difficult to decompose);
- oxidative (in the process of photosynthesis, water is enriched with oxygen);
- detoxification (plants are able to accumulate toxic substances and transform them into non-toxic ones).

When cleaning wastewater, the most common types of higher aquatic plants are used, such as reeds, lake reeds, narrow-leaved and broad-leaved rushes, combed and curly sedum, spirodella, elodea, water hyacinth (Eichhornia), yellow cockscombs, sedum, common arrowroot, buckwheat, sea sedge , urut, hara, iris, etc.

The ability of higher aquatic plants to remove pollutants from water - biogenic elements (nitrogen, phosphorus, potassium, calcium, magnesium, manganese, sulfur), heavy metals (cadmium, copper, lead, zinc), phenols, sulfates - and reduce its pollution by oil products, synthetic surface-active substances, controlled by indicators of organic pollution of the environment, such as BOD and COD, allowed their use in the practice of cleaning industrial, economic and domestic wastewater and surface runoff both in Ukraine and around the world.

Low-cost technologies of "Bioplateau" were developed and implemented by Ukrainian specialists in various countries of the world, such as Germany (city of Wisinburg), Syria (city of Aleko, textile factory "Judy"), Russia (the village of Shongo, Murmansk Region). In Ukraine, the use of higher aquatic plants on various types of bioplateau - engineering-biological structures that provide cleaning and re-treatment of household and industrial wastewater and polluted surface runoff, which do not require (or almost do not require) the consumption of electricity and the use of chemical reagents with minor periodic operational maintenance - started in the last century.

The Institute of Hydrobiology of the National Academy of Sciences, Kyiv, proposed and investigated the use of bioplateau as a water treatment facility in the channels through which water is transported from the Dnipro for the water supply of such regions as the Crimea, Donbas, as well as in other industries. Extensive study and implementation of bioengineering structures using higher aquatic plants is carried out at the Institute of Ecological Problems, Kharkiv. In 2003, at the initiative of the

Ministry of Ecology and Natural Resources of Ukraine, the National Academy of Urban Economy developed a program for the introduction of phytotechnology in Ukraine for 2005-2015.

In 2004, on the initiative of the Kharkiv regional administration, a similar program for the introduction of phytotechnology was developed.

Bioplateau structures were designed and implemented in Donetsk region, Zaporizhzhia region (Mokryansky quarry), Luhansk region (Krasnorichenske village, Parkhomenko village, Ivanivka village), Kharkiv region (Vilshany, Protopopiovka, Solonytsivka, Martova villages) , Borivske, Zolochiv, in the Kharkiv State Zoological Park).

Thus, on the basis of the conducted research, it is proposed:

- cleaning should be carried out only during the bathing season, which will eliminate the possibility of destruction of hydrotechnical structures due to possible changes in the regime of the Bolshaya Almatynka River;

- to create a bio-plateau next to Lake Sayran, to improve its recreational quality. The creation of a bioplateau also involves the creation of a dam for impregnationof water on the bioplateau (Fig. 8). The dam is proposed to be placed at the confluence of the Bolshaya Almatynka River into Lake Sayran.

Fig. 8. Bioplateau project on Lake Sayran

- to create bioplats next tothe Bolshaya Almatynka river for seasonal water purification in it. For water supply, it is planned to create two dams for the Pochaof water on the bioplateau (Fig. 9). Bioplateau is planned to be placed in the Park of the First President.

Fig. 9. Bioplateau project on the Bolshaya Almatynka River

This project envisages maintaining the physico-chemical parameters of water in Lake Sayran not lower than the third quality class.

The proposed technology has the following advantages:

- bioplateau technology is environmentally friendly and simulates the natural processes of self-purification of water;
- bioplateau during its construction is much cheaper than traditional sewage treatment plants and has low operating costs;
- the technology does not involve the use of coagulants, flocculants, ionoactive compounds, artificially cultivated strains of microorganisms-destructors, as well as forced aeration of wastewater;
- bioplateau technology is characterized by ease of construction and reliability of operation. The service life of treatment facilities without major repairs is 20 - 25 years;
- bioplateau ensures stable efficiency of wastewater treatment both in summer and in winter;
- the maintenance staff of the wastewater treatment plant complex consists of one employee who periodically inspects the facilities, organizes the cleaning of the sedimentation tank and prepares it for work in the winter period;
- if there are swampy areas of the area, it is possible to include them in the composition of treatment facilities, which significantly reduce the cost of construction and contribute to the rational use of land resources;
- the higher aquatic vegetation on the surface of the bioplateau blocks provides deodorization of domestic wastewater, therefore the size of the sanitary protection zone of the complex of bioplateau treatment facilities can be up to 50m [14].

V.CONCLUSIONS

The results of the work allow us to draw the following conclusions:

- in view of the complex hydrological regime of the Bolshaya Almatynka River, it is advisable to carry out cleaning measures seasonally during the recreational

use of Lake Sayran;

- the proposed hydrotechnical structures (dams and bioplateau), provided they are properly designed, are able to improve the recreational potential of recreation areas in the city of Almaty;
- the use of bioplateau is a low-cost and effective way of water purification in the Bolshaya Almatynka River and Lake Sayran;
- the proposed use of bioplateau will allow supportthe chemical parameters of the water in Sayran Lake are not lower than the third quality class and to significantly improve the water quality in the Bolshaya Almatynka River.

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TREATMENT OF FILTRATES OF LANDFILLS BY BIOLOGICAL METHOD

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Abstract. *Existing landfills of Ukraine today turned into powerful sources of environmental danger. The problem is specifically hectic for Ukraine since there are many landfills from Municipal solid wastes (MSW) in Ukraine that have been in a need for closing for a long time already. Same problem exists in other countries. For solution of this problem it is suggested a two-stage purification for infiltrates on landfills in Ukraine and reduction of environmental danger from their accumulation (that is observed on the example of Hrybovytske landfill). Aim of the work is to increase a level of environmental safety of hydrosphere with the help of two-stage purification of infiltrates from landfills in aerobic lagoons and municipal sewerage pollution control facilities (PCF). For achievement of the set aim the following tasks should be solved:*

-to conduct analysis of environmental danger sources of hydrosphere on the territory of Hrybovytske landfill;

-to study process of biological purification of infiltrates in aerobic lagoon in static regime;

-to set optimum conditions for biological purification of infiltrates in aerobic lagoon in dynamic regime;

-to set technological peculiarities of implementing a stage of pretreatment of infiltrates on landfills in aerobic lagoon;

-to set stability of parameters for tertiary treatment of infiltrates on municipal PCF;

Scientific part of the work lays in:

1. Setting impact of parameters in implementation process (time of delay of infiltrates in aerobic lagoon, temperature, periodicity of it) on effectiveness of infiltrates` purification in aerobic lagoon that would give opportunity to optimize purification process.

2. Studied peculiarities of biocenosis development of aerobic lagoon that enabled to prognosticate a development of biological process of infiltrates` purification.

Keywords: *aerobic lagoon*, *time of delay, biocenosis development, biological purification, optimum conditions, environmental danger.*

I. INTRODUCTION

Existing landfills in Ukraine, processes of creation and functioning of which is highly resembling for all the objects, today turned into powerful sources of environmental danger. Problems of infiltrates purification of SMW exist during all

projection period, exploitation period, and closing of the objects. It is worth mentioning that most of storage places for MSW in Ukraine are basically landfills, not polygons. Unlike SMW landfills, polygons are engineering buildings that are equipped with protection anti-filtration display, collection systems and utilization of filtrates and biogas, system of technical and biological recultivation of cards filled with wastes, harvesting system and drainage of conditionally clean atmospheric waters. In most cases all these systems (or the majority of them) on the MSW collection places in Ukraine don't exist. The problem is choosing the system of infiltrates purification at the stage of MSW landfill closing, for majority of which uncontrolled flow of infiltrates caused accumulation of their volumes in pounds-accumulators.

For purification of infiltrates before the beginning of landfill recultivation perspective is two-stage purification of landfill infiltrates in aerobic lagoons and municipal PCF, though enough reasonable scientific and practical recommendations for two-stage purification application under different conditions of different composition of infiltrates purification are absent. This has led to a need to conduct scientific research aiming setting optimum conditions for two-stage purification for landfills infiltrates in Ukraine and environmental danger elimination from their accumulation.

II. ENVIRONMENTAL DANGER OF HYDROSPHERE POLLUTION CAUSED BY FILTRATES OF MSW LANDFILLS AND ITS ASSESSMENT

Polygons of MSW – sources of chemical and biological pollution of the environment. Specifically dangerous is impact from MSW landfills on the surface and underground water that lays within the impact of these objects. MSW polygons are inseparably connected with environmental objects and influence on its compounds condition: soils, underground and surface water sources, atmosphere air, biotes. Continued accumulation of municipal wastes on landfills causes unpredictable physical and chemical and biochemical processes in liquid, solid and gas state.

MSW dumps are powerful sources of environmental pollution – atmosphere, hydrosphere, soils. Because of variety of wastes that are directed to landfills and polygons, to assess chemical composition of wastes is highly difficult. On bumps with a depth of 1,5–2 m and more there always appears grey-black coloured with BOD_5 ranging between 500 – 5000. mg/dm^3. It is so called infiltrate, very toxic substance that continuously leaks from wastes thickness. Toxicity of infiltrate doesn't reduce even after its dissolution for 100 times. As a rule, these dumps aren't equipped with anti-filtration screens, collection systems of infiltrate that creates in dump body resulting from atmospheric falls and processes of organic compounds decomposition. Soil and surface waters that leak through land covering, capture dissolved and suspended solid substances and products of biological decomposition, that's exactly why MSW leaching solutions contain different chemical elements and compounds. Volume of filtrate that creates during a year depending on climate conditions from 1 ha of waste body, reaches generally from 2000 to 4000 m^3.

1.1.Infiltrate purification technology

The most popular technologies in Ukraine are the following:

- Reverse osmosis technology;
- Technology of chemical and biological oxidation;
- Infiltrate knotting technology;
- Technology of biological purification in anaerobic and aerobic medium.

Aerobic methods of biological purification of filtrates have row of undeniable advantages over anaerobic: they are flexible in using, fast include in stationary regime of work, fast accommodate to changeable composition and expanses of filtrates. Aerobic reactors are far more simpler in construction and far more cheaper than anaerobic, they are also much easier automatized and easier in exploitation.

From analysis of existing natural studies it is possible to make conclusion, that purification of infiltrates in aerobic lagoon (or simultaneously connected lagoons) is simply, low-budget and enough efficient method of pretreatment of infiltrates.

2.CHARACTERISTIC OF HRYBOVYTSKE (LVIV) LANDFILL

The dump has started to exist since year 1969, according to different information sources its space reaches from 33,3 ha to 45,3 ha, accumulated wastes reach maximum height of 45 m.

The body of MSW Hrybovytske landfill reaches around 12 – 15 mln. tons of wastes. Specifically hazardous effect on the environment around MSW Hrybovytske landfill territory have four pound-accumulators of acid flux tars (one of them is filled with wastes). General space of flux tars reaches around 5 ha. Level of infiltrate danger - «extremely hazardous», and danger class of infiltrate on MSW Lviv landfill reaches 1.

3.METHODOLOGY OF LABORATORY EXPERIMENTS OF INFILTRATES` AERATION AND METHODOLOGY FOR RESEARCH OF INFILTRATE TERTIARY TREATMENT STAGE ON MUNICIPAL PCF

3.1.Study of the aerobic purification was conducted at plant (Ill. 2.1).

The plant contained from 5-litter bulb, that with volume of 4 l was filled with infiltrate. Infiltrate for studies was chosen from pound-accumulator of Lviv MSW For aeration the air was supplied to bulb with the help of laboratory compressor. With the help of regulation compressor, set on air flow tube, it was regulated air expanses on aeration and supported constant significance of this expanse throughout the whole experimental time.

Fig.1. Scheme of experimental plant for infiltrate aerobic purification.

In bulb there was set an aquarium aerator, via which division of air took place in bulb volume. After some periods of time from bulb was taken probes, that were analysed on ammonium nitrogen content, COD, it was set also a content of dissolved oxygen and hydrogen indicator pH.

Experimental work was conducted in two stages.

At first stage (static) was set alteration of COD, concentrations of ammonium nitrogen, pH and concentration of dissolved oxygen under conditions of continuous aeration without allotment of pretreated infiltrate and accordingly without addition into volume `fresh`, untreated infiltrate.

At second stage (dynamic) that was conducted after obtaining maximum possible level of purification under static regime, it was modeled continuous regime of purification, that is planned to be implemented at industrial pollution control facility. Once in 24 hours from bulk it was taken certain amount of infiltrate and was poured same amount of `fresh` unpurified infiltrate. For certain proportion significance of the sample the researches were conducted for obtaining constant concentrations of ammonium nitrogen and COD. After that, the daily volume of purified and `fresh` infiltrate was substituted, that accordingly was collected and poured into aeration plant, and it was studied a process of aerobic purification in dynamic regime for another time significance of infiltrate delay in aeration zone. Once in a day an infiltrate sample from bulk for analysis and sample for addition of infiltrate were taken.

3.2.Methodology of tertiary infiltrate treatment research at PCF

Studies on infiltrates` impact on process of biological purification at sewerage pollution control facilities of Lviv city were conducted at experimental plant, displayed at Illustration 2.2, that imitated sewerage pollution control facilities. The studies were held in static and dynamic regimes.

For experiments in static regime for research place a mixture of effluents with active sludge was taken. Infiltrate in quantity of 1 m^3 was selected from pound-accumulator №5 in MSW Hrybovytske landfill. In experimental aeration plant was poured mixture of effluents and active sludge and was added calculated quantity for obtaining mixtures, that met the following dissolving criteria: 10; 500; 1000; 1250; 1500. In reactor it was added mixture of effluents with active sludge till obtaining general volume in 1,64 m^3. After that samples were taken for chemical experiments and the plant was launched. Every study cycle in static regime lasted 6 hours. After finishing of air supply a sample was taken for conducting chemical experiments.

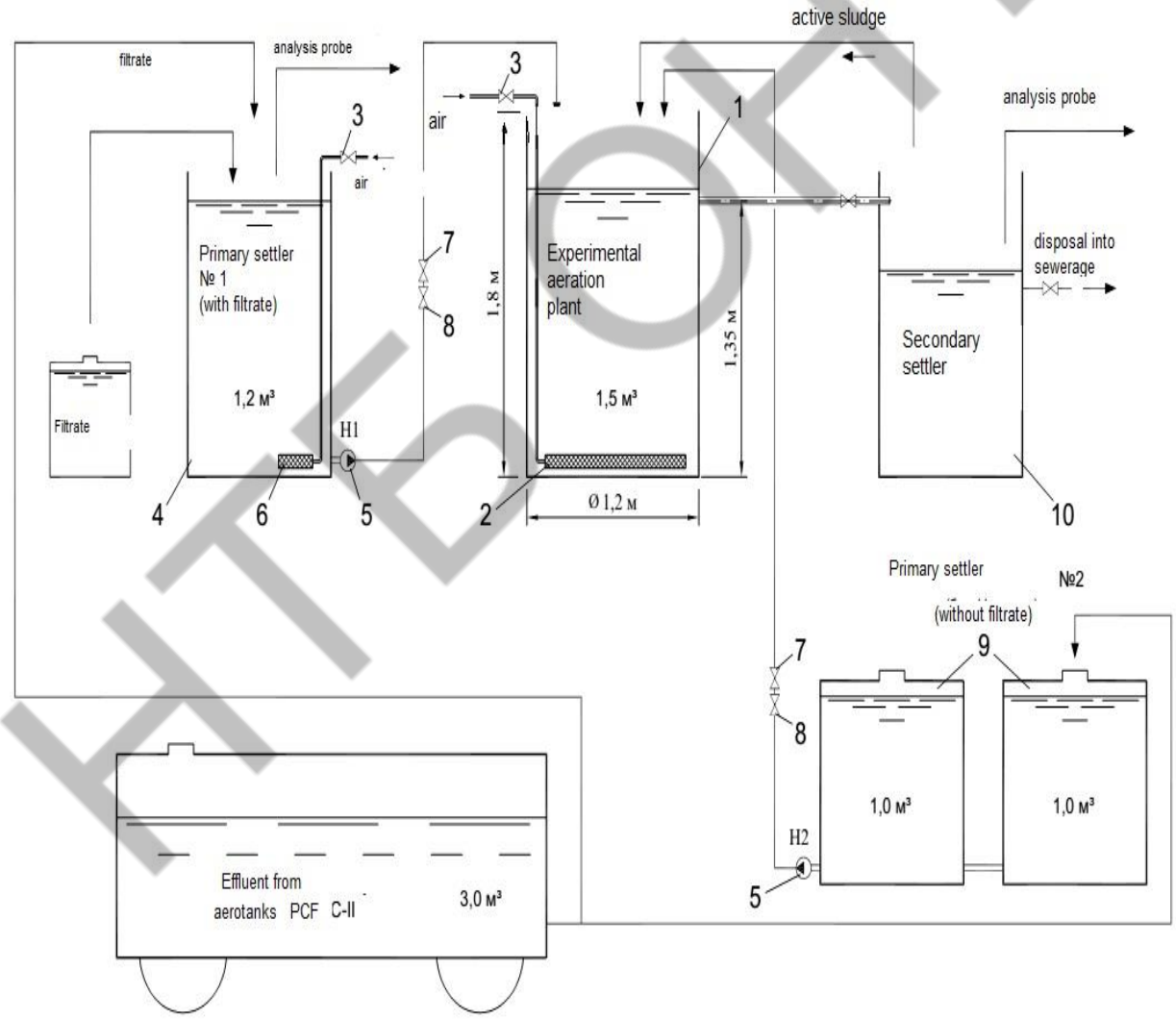

Fig.2. Basic technological diagram

Experiments in dynamic regime were conducted at the same plant (Ill.2.2.) The plant contained primary settlers: primary model settler for mixture of effluents with infiltrate and primary model settler for effluents without infiltrate. During 8 daily experiments the mixture from effluents and infiltrate as equally carried to aeration plant 1. Regulations of expanses were carried with the help of circulation pump and valve. Homogeneity of the mixture was obtained with the help of aerator. After 8 hours of mixture supply from effluents with infiltrate it was modeled working process of aerotank during 16 hours without adding infiltrate.

4.GENERAL STRATEGY FOR TWO-STAGE CULTIVATION OF LANDFILL INFILTRATES

Analyzing research data it is recommended principal scheme for implementation of landfill infiltrates pretreatment technology that is illustrated in fig.3. According to this scheme, infiltrates are accumulated in pound-accumulator that simultaneously serves as aerobic lagoon.

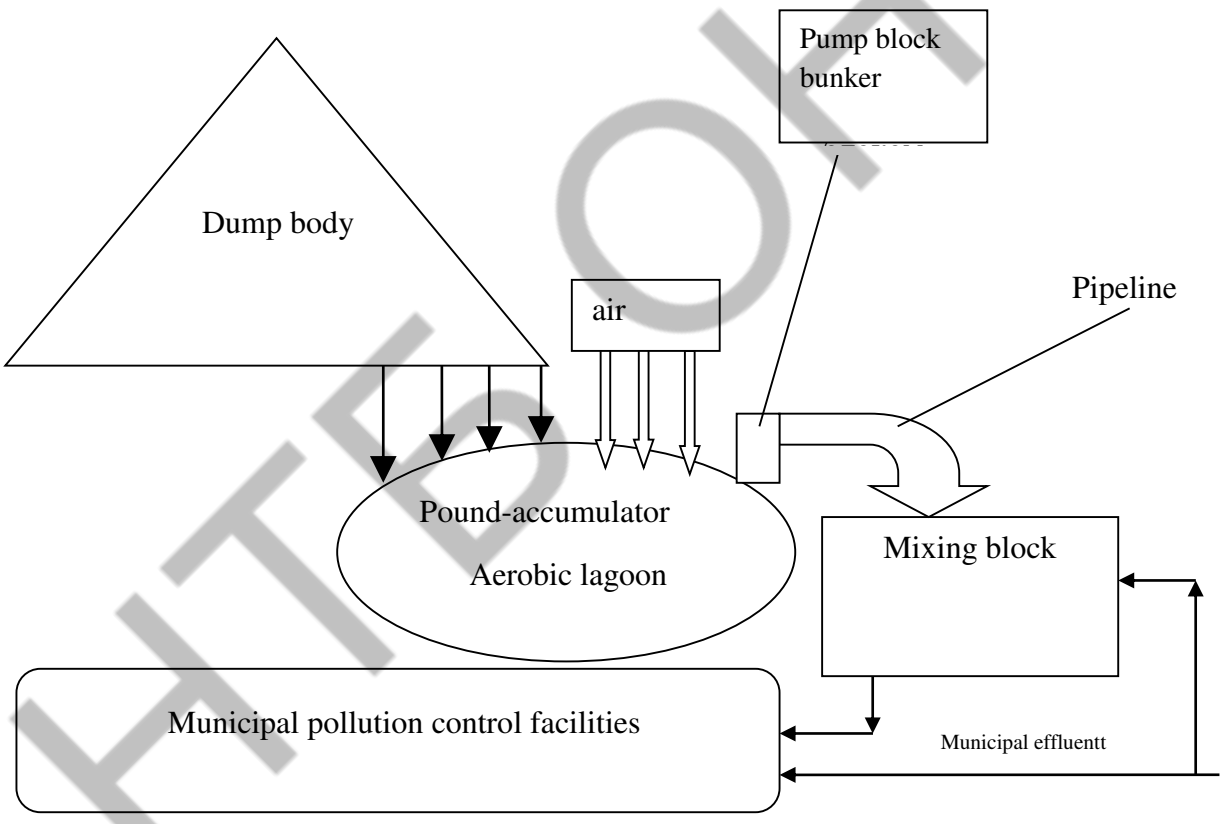

Fig.3. Principal scheme of two-stage landfill infiltrate purification in aerobic lagoons and at municipal pollution control facilities.

For this it is equipped with aeration system. Pound-accumulator is being screened with protective display by using well known technologies. In aerobic lagoon biological aerobic oxidation is taking place of organic contaminants and of ammonium nitrogen. Constant inflow is being realized and harvesting of infiltrates under conditions of supplement with necessary period of infiltrate residence in reactor.

Infiltrate collection is being done with the help of pump station throughout set pipeline «landfill – municipal PCF» infiltrate is transferred into mixing block PCF where at given proportion it is mixed with municipal effluents and in mixture is directed to tertiary treatment at municipal PCF. For every particular case for technology implementation it is necessary to make balance calculation. In ratio of Lviv PCF it is set the following input of infiltrates: 1) infiltrate disposal into system of city sewerage of Lviv is necessary to conduct from 09 am to 5 pm with gradual productivity increase from 10 m^3/hour to 25 m^3/hour; 2) it is necessary to cease disposal of infiltrate under nonfavourable climate conditions, particularly: under exceed of temperature of effluents in aerotanks КОС-II over 20 ^oC and its reduction under 10 ^oC.

Concerning two-stage scheme for infiltrate purification application at other objects, then in every particular case it is necessary to make additional calculations and based on their results to set optimum regimes for infiltration pumping.

CONCLUSION

An identification of environmental danger sources was conducted on the impact territory of Hrabovytske landfill. It was set, that in the hazardous impact zone of Hrabovytske landfill it is possible to distinguish three potential sources of environmental danger: stored MSW, lakes from crude oil recycling and industrial activity of the population. It is impossible to concretize an impact from every form of the source, yet it is possible to judge which type of contamination is causing each from the sources.

Ukrainian landfills create consistent environmental danger in their impact zone because of absence of protection anti-filtration screen, collection system and utilization of filtrates and dump gas, plants system of physical and biological recultivation of cards filled with wastes, harvesting systems and drainage of conditionally clean atmospheric waters. Analysis of possible technologies for purification of accumulated infiltrates has shown perspective to apply technologies for biological purification of infiltrates in aerobic lagoons.

Suggested two-stage purification scheme of landfill infiltrates enables to purify infiltrates effectively with primary purification under conditions of aerobic lagoon on the territory of landfill, transporting of infiltrate with the help of pipeline «landfill – municipal PCF», dissolving it with municipal sewerage effluents and pretreatment on municipal PCF. To apply the two-stage infiltrate purification scheme on proper objects, in every concrete case it is necessary to make additional equations and calculations and on their result bases to set optimum regimes of pumping over the infiltrate.

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INNOVATIVE TECHNOLOGIES FOR THE DISPOSAL OF SEDIMENTS FORMED AT TREATMENT PLANTS IN UKRAINE AND POLAND

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Abstract. *Continuously growing human economic activity has gained such strength that at the present stage it is ~ 10% of the productivity of the entire biosphere of the Earth and covers 61% of the earth's surface. As a result of human economic activity, a large amount of waste enters the environment. Most often, such waste is stored in specially designated areas, but over the decades, such storage sites have become overcrowded, and therefore began to negatively affect people and the environment. In recent decades, scientists, not only in Ukraine but also in the world, have attracted special attention to the problem of rapid growth of sewage sludge (ERU), which is a large tonnage of biological wastewater treatment, so this work is very relevant.*

The purpose of this work is to establish the possibility of using for biological reclamation of the substrate based on sewage sludge.

To achieve this goal it is necessary to perform the following tasks:

- to determine the sanitary-microbiological and ecological-chemical characteristics of the accumulated SS;

- determine the quality of fresh SS;

- to conduct bioindication of substrates on the basis of settled and fresh SS;

- to study the influence of different types of substrate on the germination, growth and development of bioindicator plants;

- to establish the dependence of changes in growth and development of plants depending on

different types of substrate;

- to determine the optimal composition of the substrate for biological reclamation.

Keywords*: sewage sludge, biological reclamation, substrate, sanitary-microbiological and ecological-chemical characteristics, bioindication.*

I. FORMULATION OF THE PROBLEM

Sewage sludge is a by-product of wastewater treatment technology. It contains more than half of the pollutants inflowing to the treatment plant with raw sewage [Bauman-Kaszubska and Sikorski, 2008]. According to polish legal acts municipal sewage sludge is defined as sludge from fermentation chambers and other installations used for treating sewage [Act of 14 December 2012 on Waste]. Wastewater treatment is always accompanied by the generation of sludge, which is defined as organic-mineral solid phase separated from wastewater. Sludge is also defined as a mixture of water and solids separated from various types of sewage by natural or artificial processes. In specialized literature municipal sewage sludge is defined as sludge

resulting from the treatment of municipal wastewater. Raw sludge is defined as untreated sludge coming directly from wastewater treatment processes (this sludge rots easily and gives off unpleasant odours).

Until recently, the main methods of wastewater disposal were dumping and storage on sludge sites (landfill), but such methods of disposal are expensive and environmentally friendly, so in recent decades, actively began to use other methods of wastewater disposal: incineration, use as fertilizer in agriculture, etc. Important in the disposal of sewage sludge are the processes of pre-treatment of sludge, which include stabilization by adding lime, composting, aerobic or anaerobic conversion, as well as dehydration and drying processes.

Initial sludge is produced by sedimentation of easily settable suspended solids (organic and mineral - not kept in grit chambers) in preliminary settling tanks. These sludges are unmixed with other recirculated sludges. Secondary sludge is separated in secondary settling tanks after biological wastewater treatment in activated sludge flow devices or in biological beds. Secondary sludge, when returned to the biological reactor, is called recirculated sludge, whereas sludge removed from the wastewater treatment system due to biomass growth forms excessive sludge. Mixed sludge is usually obtained by mixing primary and secondary sludge. Different types of waste and sewage sludge generated at wastewater treatment plants are depicted in the Figure 1.

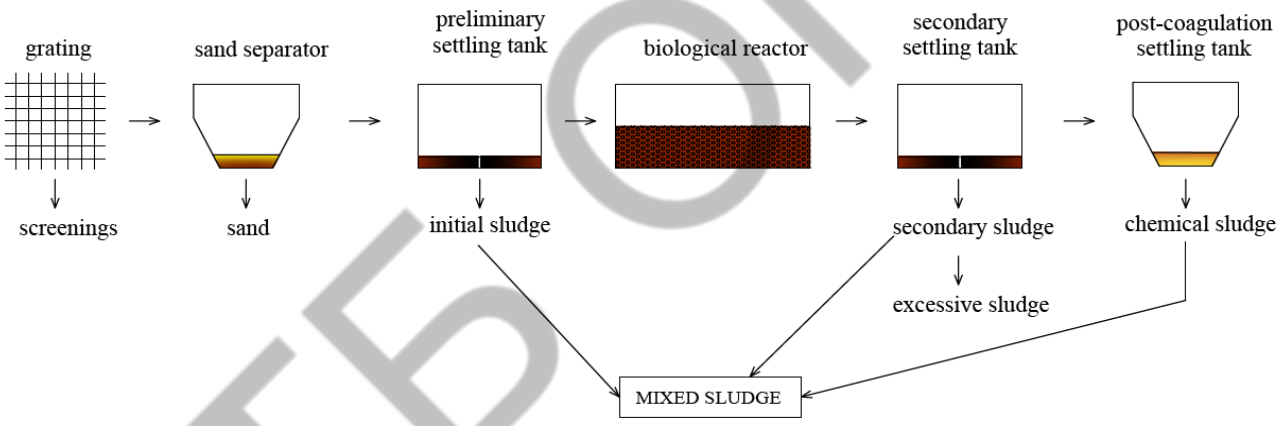

Fig.1. Types of waste and sewage sludge generated at the wastewater treatment plant

It is estimated that sewage sludge generated after wastewater treatment constitute about 1-5 % of wastewater volume that flows into the treatment plant. Sewage sludge is characterised by high hydration level (up to 95-99%) which is connected with its liquid consistency and poor drainability. Moreover, it shows significant content of easily decomposable organic matter which causes its high tendency to decay. Sewage sludge contains many compounds that are harmful to the environment, but also a lot of nutrients and organic substances valuable for agriculture, such as nitrogen and phosphorus. Sometimes industrial sewage sludge can also include some so called new-generation pollutants- pharmaceuticals, personal care products, plasticizers, specific or toxic pollutants such as: heavy metals, dioxins, furans, pesticides and others, depending on the type of industry.

In the European Union, the most common methods of pre-treatment of SS are aerobic and anaerobic conversion. Studies have shown that in the case of aerobic

conversion in sewage sludge in large quantities of humic acids are formed, and as a result of anaerobic digestion the main components that are formed are proteins and aromatic amino acids, which allows the use of SS in agriculture.

RESEARCH OF WAYS OF DISPOSAL OF WASTE ACTIVE MUD IN UKRAINE

For research in this work were used sewage sludge treatment plants (WWTP) of Lviv. selected at the Lviv CBS contain sufficient amounts of phosphorus, potassium and nitrogen, and heavy metals do not exceed the maximum allowable concentration (MPC). At the time of sampling (June 2019), sludge sludge from sewage treatment plants was finely dispersed, and in some places water-saturated sludge.

Sampling of the accumulated sediments was performed using a metal cylindrical tube, such as a chute, with a lower valve. The diameter of the sampler was 128 mm, length 1 m. A pipe was screwed to the upper part of the sampler, the length of which was increased by means of couplings.

The thickness of the sludge was 3 m or more. Samples were taken in the range of depths 0-0.2 m; 1.4-1.6 m Length; 2.8-3 m. Such intervals were chosen in order to investigate the ecological-biogeochemical and parasitological characteristics of silt in the near-surface, medium-depth and bottom conditions of their stay. The volume of the sample was 2.5 dm3. The selected sediment samples were packed in double plastic bags. Each sample was assigned a serial number. Sample numbers were recorded in the sampling log. The coordinates of the sampling points were measured and tied to the area with the help of geodetic instruments. Fresh sediments were collected immediately after unloading from the centrifuges. The selected sediment samples were packed in a plastic bag.

To study the quality of the growth substrate (bioindication), two species of plants were selected, which belong to one of the categories. Category 1 - monocotyledonous plants: rye, ryegrass, rice, oats, wheat, barley, sorghum, corn. Category 2 - dicotyledons: white mustard, canola, radish and wild turnip, Chinese cabbage, watercress, tomato, bean. Before using the seeds of each crop, analysis was performed and the energy of their germination was determined. In each of the vessels were planted 10 identical seeds of the selected species. For each replicate in each embodiment, the percentage of seed germination relative to the average germination in the control vessels was calculated. The length of the longest roots of each plant was measured and the average length of the longest root for each investigated growth substrate was determined. Statistical analysis was used to determine the smallest significant discrepancies between controls and test concentrations.

For the study, in accordance with this method, we used different types of substrate based on soil, SS and natural sorbents, which were compared according to the control soil.

To determine the quality of the growth substrate from the above plants used: barley (Hordeum vulgare), white mustard (Sinapis alba), watercress (Lepidium sativum) and ryegrass (Lolium perenne).

Since, in recent years in Ukraine there is a growing need for biological reclamation of spent man-made objects (landfills, dumps, quarries, etc.), and this

process requires significant resource and energy costs, finding ways to reduce its cost and preserve natural resources. resources is extremely important and promising. Therefore, great attention in solving this problem should be paid to the possibility of using in the biological reclamation of man-made waste, such as SS. As a result, it is possible to simultaneously address two extremely common environmental problems and offer a technological solution for the use of nutrients from SS and provide them with the process of biological reclamation.

The first stage of research was carried out with dark gray podzolic soil, to which was added settled sewage sludge (for this fresh selected sludge was stored without access of oxygen for 6 months to simulate the conditions of accumulation of sludge on sludge sites) in the ratio (%): 100: 0; 80:20; 60:40; 40:60; 20:80; 0: 100. The created substrate was placed in Petri dishes and 10 seeds of common barley (Hordeum vulgare), white mustard (Sinapis alba) and watercress (Lepidium sativum) were planted in it. For the reliability of the studies, the experiments were performed in quadruplicate. In fig. Figure 2 shows the general appearance of bioindicator plants (white mustard) in the experimental substrates.

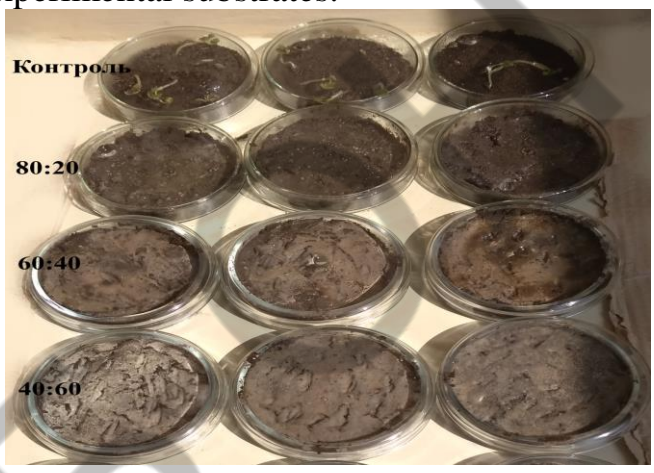

Fig.2. General appearance of white mustard in experimental samples on day 10

As can be seen from Fig. 2 germination of white mustard is not observed in any sample except the control sample. According to the results of the first experiment, we found that even a small proportion of sewage sludge (20%) in the substrate, with this type of storage has a very negative effect on the germination of all plant species. And in samples with a sediment content of more than 40%, the development of dangerous fungi and mold is observed.

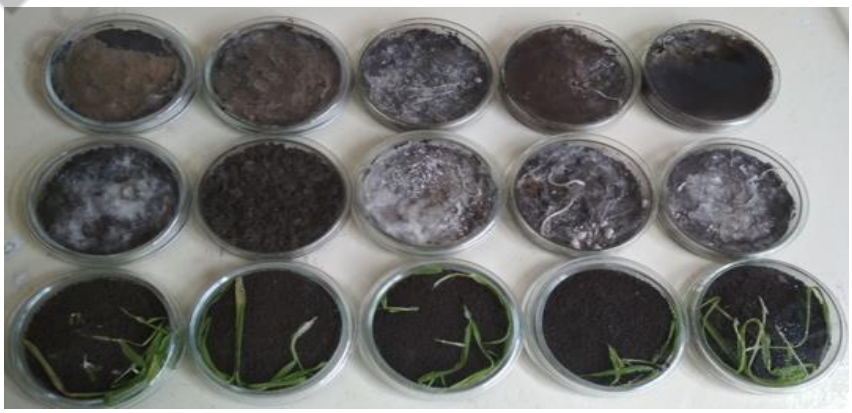

Fig. 3. The appearance of fungi and mold in the studied samples

In parallel, at the same stage, an experiment was set up in which dark gray soil, settled sediment and heat-treated settled sediment (dried in a drying chamber for 2 hours at a temperature of 105 ºC) were used, which were mixed in the ratio (%): 60:40 ; 20:80; 0: 100. To determine the quality of the growth substrate in Petri dishes were planted 10 seeds of barley in the substrate with heat-treated sediments and 10 seeds of barley, which were etched with a disinfectant Vitvax 200 FF, v.s.k. (consumption rate of 3 l / t of seeds). The experiments were performed in triplicate. The results of the second experiment are presented in Fig. 4.

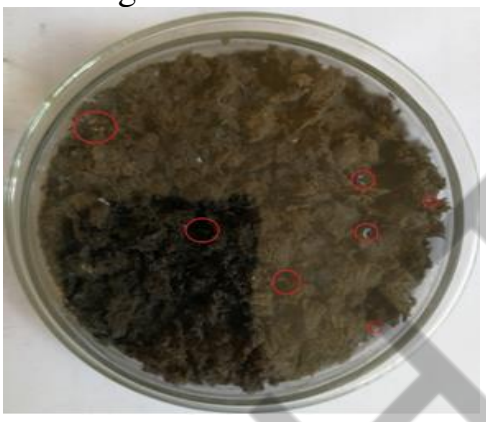

Fig. 4. The appearance of pathogenic microflora in the sample with heat-treated sludge

As can be seen from Fig. 3, in the case of using heat-treated sludge, it is possible to observe the development of pathogenic microorganisms that are dangerous not only for plants but also for the soil. Also, it should be noted that the use of pickled seeds did not give results, plant germination was not observed in any sample other than control.

Therefore, based on the results of the first stage of research, it can be concluded that the main problem for the use of sediments is their disinfection, because this method of storage develops a significant number of fungi and pathogenic microflora.

The second stage of research was carried out with dark gray podzolic soil, to which fresh sediments were added in the ratio (%): 100: 0; 80:20; 60:40; 40:60; 20:80; 0: 100. Bioindication was performed in Petri dishes by planting 10 seeds of pickled (Vitavax 200 FF) barley (germination 95-97%), barley (germination 95-97%) unfermented and watercress (germination 92-95%). To ensure the reliability of the research, the experiments were performed in quadruplicate. Upon completion of the study, the length and weight of the aboveground part and roots were measured. The results of the bioindication on the experimental substrates are presented in Fig. 5.

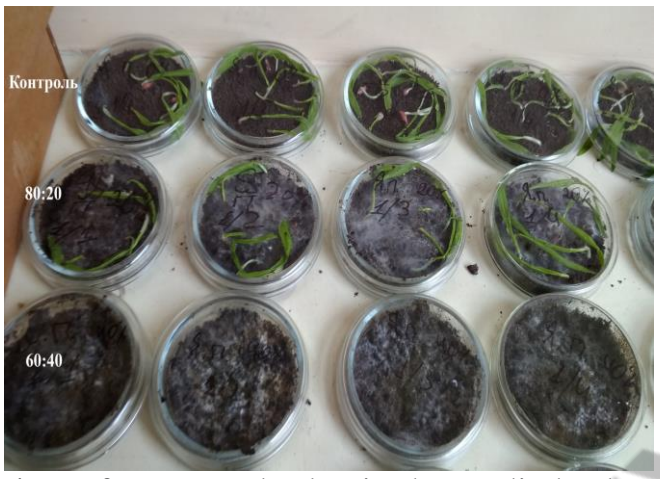

Fig.5.General view of common barley in the studied substrates on day 10

On the 10th day of the study, the number of seedlings of bioindicator plants did not differ much from control samples (pickled barley - 17.5%, watercress - 15%, and in untreated barley even exceeded them by 2.5%). With a content of 40% of sediments in the substrate in samples with pickled barley, there was a much greater impact on plant growth and development, namely: total plant weight ≈18.5%, height of the ground from -25.8 to -54.6%, and for roots from -65.1 to -87.8%.

Therefore, as a result of the analysis of the results of the second stage of research it was found that fresh sewage sludge according to the results of laboratory studies contains a significant proportion of nutrients, and therefore can be used in the mixture to create a substrate. In addition, in the case of adding 20% of ERUs to the substrate, there is a positive effect on the growth of the aboveground part (stem) of barley.

After analyzing previous studies in the third stage, it was decided to add to the substrate sorbents of natural origin, to improve its quality and binding of mobile forms of hazardous compounds.

At this stage of the research, fresh sediments were added to the dark gray podzolic soil in the amount (%): 0; 20; 25; 30; 35; 40. In the same substrate in the amount (%): 0; 5; 7.5; 10 added natural zeolite. For the reliability of the experiments were performed in triplicate.

Bioindication was performed in Petri dishes by planting on the created substrate 10 seeds of barley (germination 95-97%). Upon completion of the study, the length and weight of the aboveground part and roots were measured.

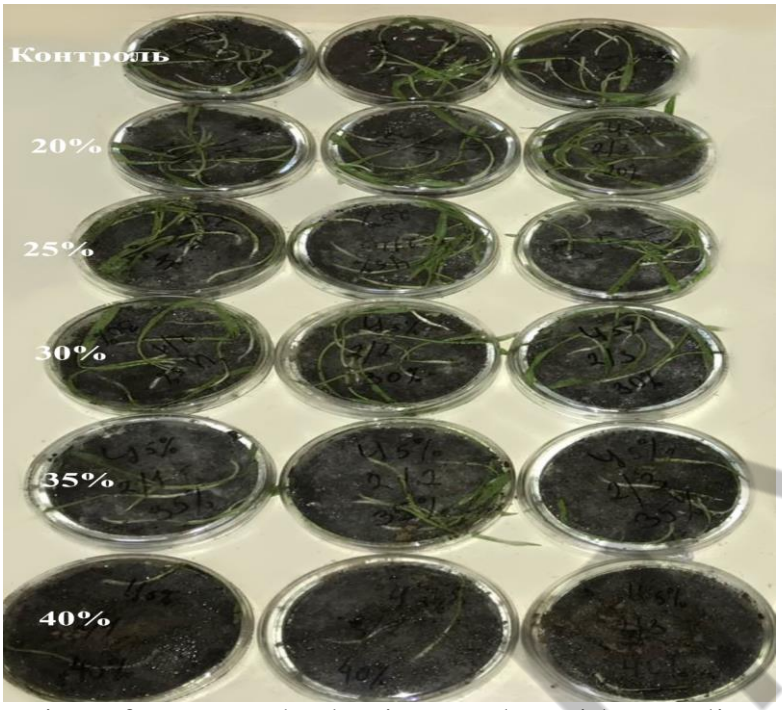

Fig.6. Germination of common barley in samples with a zeolite content of 5% per 10 days

According to the obtained data, the best growth rate of the terrestrial part of the plant is observed in the substrate with a ERU content of 35% and a zeolite content of 7.5%.

After analyzing previous studies in the fourth stage, it was decided to conduct studies with two types of natural sorbents.

At this stage, the study was performed with two types of substrate: the first added dark gray podzolic soil, fresh ERUs and zeolite, the second - dark gray podzolic soil, fresh ERUs and glauconite in the ratio (%): 50:40:10. Comparisons were performed with the control sample (soil). Bioindication was performed in plastic cups (volume 500 ml) by planting 10 seeds of barley (germination 95-97%) and 30 seeds of ryegrass (germination 90-93%). To ensure the reliability of the data, the experiments were performed in triplicate.

Fig. 7. General appearance of plants for 10 days

Fig. 8. General appearance of plants for 20,30,40,60 days

Thus, based on the results, we can conclude that in the case of adding two different types of natural sorbents (zeolite and glauconite) to the substrate, there are positive changes in germination, growth and development of bioindicator plants (barley and ryegrass). In addition, it should be noted that this composition of the substrate has a positive effect on the growth of ryegrass, which is an energy plant.

PROBLEMS OF DISPOSAL OF WASTE ACTIVE MUD IN POLAND

In Poland the basic legal act concerning sewage sludge is the Act of 14 December 2012 on Waste. According to it, every waste is identified by its own numerical code and thus 19 08 05 is the waste code of "stabilized municipal sewage sludge". Stabilization means the process by which organic substances from sewage sludge are transformed into inorganic substances or very poorly degradable material. The same deed states that the use of municipal sewage sludge is possible, when it is stabilized (i.e. with significantly reduced susceptibility to rotting, in which the organic matter content has been reduced by at least 38%) and after being prepared appropriately for the purpose and manner of its use.

Sewage sludge can be either treated within the installation of the wastewater treatment plant or it can be subjected to neutralisation or recovery outside it, in specialised processing plants. Sewage sludge disposal processes include storage of thermally treated or stabilized waste at hazardous waste landfills. On the other hand, in strong accordance with polish regulations, sewage sludge can be also recovered by being used as biomass, for industrial purposes, for agricultural use, for land reclamation or for composting. National Waste Management Plan 2022 and Strategy for dealing with municipal sewage sludge for 2019-2022 are another polish legal acts concerning waste management. According to them in 2016 the most common way to manage municipal sewage sludge was to use it in agriculture. Detailed information on different ways of municipal sewage sludge management in 2016 is presented in the Figure 9.

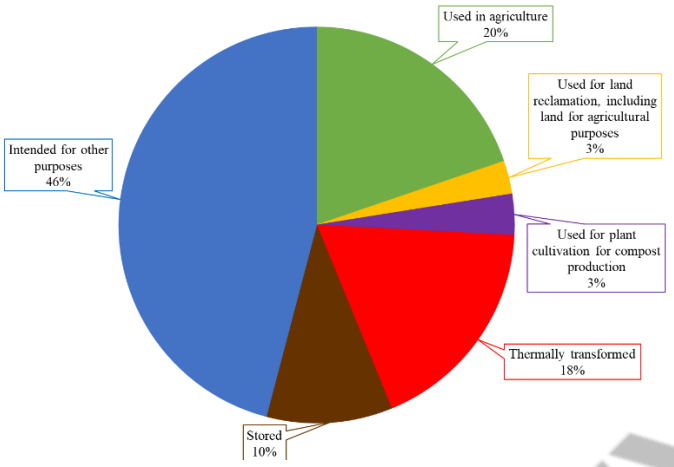

Fig.9. Ways of municipal sewage sludge management in 2016 [CSO 2016]

In recent years there can be observed an increased interest in the issue of sewage sludge management, useful components are recovered and simultaneously soils and waters are protected from contamination with heavy metals or pathogens contained in sewage sludge. Different physical, chemical and filtration properties of sewage sludge means that its processing and final treatment (disposal) requires an individual approach in each case. The main purpose of sludge treatment is to change its physical-chemical composition, reduce its volume, hydration and the concentration of organic matter, eliminate parasites and pathogenic bacteria and prepare them in such a way that it can be ultimately utilised. The fundamental problem with sewage sludge management is that there is no "typical" sewage sludge. Consequently, there is no one right solution for all wastewater treatment plants. Moreover, the amount of sewage sludge generated depends on the content of organic and mineral pollutants in wastewater, wastewater treatment technology, method of sludge stabilization or reagents used in wastewater treatment and sludge treatment. Other amounts of sludge are generated at household wastewater treatment plants and others in collective facilities.

NON-TRADITIONAL METHODS OF SEWERAGE MUD DISPOSAL IN POLAND

Conventional methods of sludge dewatering and stabilization are costly and energy-consuming. This is a very important especially for small wastewater treatment plants (serving up to 2 000 P.E.), which have very limited budgets. At present, sludge produced in household wastewater treatment plants are usually transported by septic trucks to collective facilities which is very inconvenient and expensive for the user of an object. Therefore, sludge is sometimes (although this is unacceptable) discharged in an unstabilized state into the natural environment, which may cause its pollution and degradation.

There is a strong need to find different low-cost solutions for solving the problem of sewage sludge treatment and disposal on a local scale. One of them is a method that simulates processes occurring in natural marsh ecosystems, called the constructed wetland method. This involves the use of specially constructed ground and plant beds planted with water-loving plants such as: water club, rush, calamus, wicker and the most often - common reed (Phragmites Australis). The presence of such plants allows

faster drainage of sludge and development of heterotrophic microorganisms. Thanks to its porous tissue called arenechyma, common reed has the ability to absorb water from sewage sludge and then release it to the atmosphere through evapotranspiration. Another phenomenon affecting sludge dewatering in reed beds method is water leaching, which occurs due to gravitational forces. In turn, transport of oxygen through leaves and stems from the atmosphere to the underground system of rhizomes and roots allows the formation of oxygen micro-zones there. Dewatered sludge in reed beds is also subjected to stabilization as a result of biochemical transformations occurring in the vicinity of reed roots. Constructed wetland systems with common reed for sewage sludge utilization are simple to build and inexpensive to operate, moreover their natural appearance allows them to be easily incorporated into the existing landscape. Sewage sludge brought to the reed beds is not removed for a long time, even for 10-15 years. The Figure 10 shows a scheme of an installation for sewage sludge dewatering.

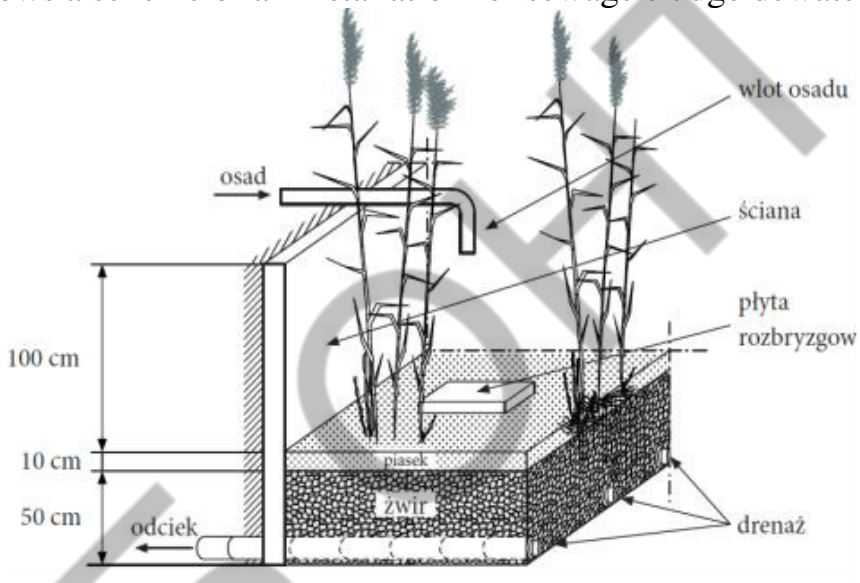

Fig.10. A scheme of an installation for sewage sludge dewatering

The method of reed bed systems for sewage sludge utilization has been known and used since the late 1980s in many European countries, including France, Denmark. In Poland, reed bed facilities are in operation, among others, at a household constructed wetland wastewater treatment plant in small Dąbrowica village near Lublin or at a big constructed wetland system near the Bialskie Lake in Dębowa Kłoda village (Figure 11).

Fig.11. Constructed wetland system with common reed for sewage sludge dewatering in Dąbrowica

The primary task of reed bed systems is to ensure the proper course of processes of dewatering and stabilization of the delivered sewage sludge. Stabilization processes reduce the intensity of unpleasant odours. Progressive stabilization is indicated by a decrease in organic matter concentration. During the dewatering process, the initially liquid sludge (99% of hydration) is transformed into a solid form. This contributes to a significant reduction in its volume. Increase of dry matter concentration of sewage sludge by 7% results in an 87% reduction of its initial volume. The efficiency of sludge dewatering in reed bed systems is comparable or higher than the efficiency of mechanical facilities. The advantage of constructed wetland systems compared to mechanical facilities is that they require significantly less electrical energy than mechanical.

Another type of promising technology is the application of an innovative installation for dewatering and disposal of sewage sludge produced in household wastewater treatment plants, constructed according to the Patent No. 218897 for the invention "Installation for sludge dewatering" of 19.06.2015. A technological scheme of the installation for dewatering and disposal of sewage sludge from the settling tank of the household wastewater treatment plant is shown in the Figure 6.

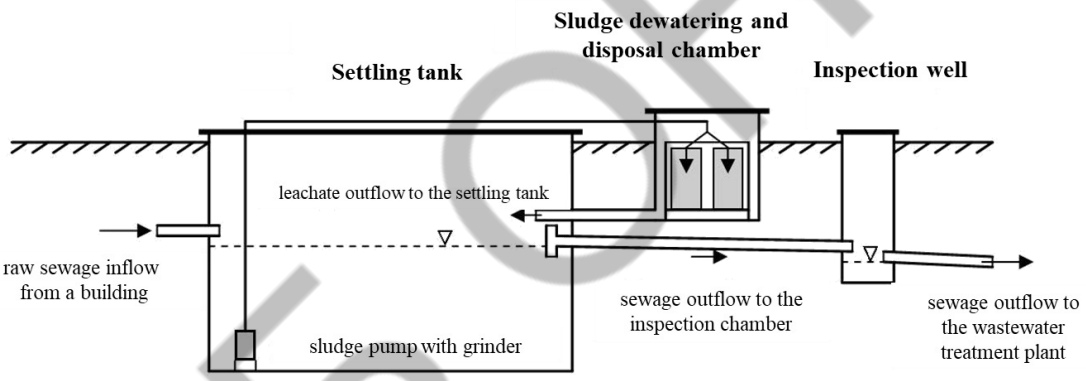

Fig.12. Technological scheme of the installation for dewatering and disposal of sewage sludge from the settling tank of the household wastewater treatment plant

The chamber for sludge dewatering and disposal is made of concrete circles in which a filter element in the form of water-repellent fabric bags is detachably mounted. In order to dewater sludge, the sewage sludge pump with grinder periodically switches on and sludge is pumped from the settling tank to the filtration unit where sludge is collected, while drained wastewater returns to the settling tank through the drain pipe. At the same time, from a special dosing device some substance is fed to the filtration unit, which hygienises the sludge and accelerates its transformation into compost, for example a complex bacterial preparation. After pumping is completed and the sludge is drained, the filter element is removed together with its contents and can be prepared for use as a fertilizer for agriculture. Numerous practical applications show that the use of some microbiological preparation can effectively support the process of dewatering and disposal of sewage sludge from wastewater treatment plants.

Fig.13. Installation for dewatering and disposal of sewage sludge produced in household wastewater treatment plants.

Fig. 14. Installation for dewatering and disposal of sewage sludge. a- in Florianka in the Roztocze National Park, b- in Stare Załucze in the Polesie National Park

The innovative installation for dewatering and disposal of sewage sludge has been already implemented in some household wastewater treatment plants in Poland, for example in Florianka in the Roztocze National Park or in Stare Załucze within the area of the Polesie National Park. Moreover, it is not necessary to transport later the disposed sludge to its destination.

CONCLUSIONS

According to the obtained research results, it can be concluded that: in case of addition of settled sediments to the substrate, inhibition of growth and development of bioindicator plants is observed due to the content of pathogenic microflora, fungi and mold in them; in the case of adding fresh sediments to the substrate, plant germination occurs only in samples where the sediment content does not exceed 40%; in the case of adding an additional component (natural zeolite) to the substrate, there is a positive effect on the germination of bioindicator plants. The best germination rates are observed in samples with a sediment content of 40% and a zeolite content of 7.5 and 10%, respectively.

Sewage sludge management is an integral part of wastewater treatment. The main purpose of sludge treatment is to change its physical-chemical composition, reduce its volume, hydration and the concentration of organic matter, eliminate parasites and pathogenic bacteria and prepare them in such a way that it can be ultimately utilised.

There are many different ways of sewage sludge disposal. Different physical, chemical and filtration properties of sewage sludge means that its processing and final treatment (disposal) requires an individual approach in each case.

Constructed wetland systems with common reed for sewage sludge utilization are simple to build and inexpensive to operate, moreover their natural appearance allows them to be easily incorporated into the existing landscape. The efficiency of sludge dewatering in reed bed systems is comparable or higher than the efficiency of mechanical facilities.

An innovative installation for dewatering and disposal of sewage sludge constructed according to the Patent No. 218897 for the invention "Installation for sludge dewatering" is a compact solution that enables the disposal of sewage sludge produced in household wastewater treatment plants.

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ANALYSIS OF BIOLOGICAL METHODS OF WASTEWATER TREATMENT

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Abstract. *Purpose of the work is to analyze existing wetland systems, biotechnologies on using hydrobionts and aerated lagoons in wastewater treatment systems. Task of the work is to elaborate experimental wastewater plant unites based on its function characteristics for suggesting improved models. Relevancy of the work is the increasing environmental pollution caused by wastewaters and urgent need for improved implemented wastewater treatment systems. Study methods used in the work included general scientific methods as system analysis, induction, deduction. Obtained results of experimental studied concluded the following: the efficiency of different pollutants removal is higher in hybrid constructed wetlands than in one-stage systems; hybrid constructed wetlands not only resolve ecological problems about wastewater management but can also provide landscape and educational profits because of their interesting shapes and innovative methods used; long term research on the operation of constructed wetland systems in Poland indicate that these systems can be used with great success on rural areas, especially in protected areas and valuable landscapes in Ukraine; cyanobacteria biomass, released from cultural medium, can be used for production of small tonnage valuable products with unique properties, large tonnage biomass of natural origin can be used for fuel production (biomethane, bioethanol, biodiesel); suggested two-stage purification scheme of landfill infiltrates enables to purify infiltrates effectively with primary purification under conditions of aerobic lagoon on the territory of landfill, transporting of infiltrate with the help of pipeline «landfill – municipal PCF», dissolving it with municipal sewerage effluents and pretreatment on municipal PCF.*

Keywords: *wetlands, aerated lagoons, wastewater treatment, biofuel production, cyanobacteria, hydrobionts, biomass.*

I. PERSPECTIVE OF USING WETLAND SYSTEM IN POLAND

Recent solutions for wastewater treatment in Poland are household wastewater treatment plants that in Poland can be defined as objects that support up to 50 people and their maximum capacity is 5 $m^3 \cdot d^{-1}$ [Water Law 2017, Poland]. There can be enumerated many different types of them and the most important ones are the facilities with drainage pipes, with active sludge, with biofilter, hybrid systems (active sludge+biofiter) and constructed wetlands [Jóźwiakowski et al. 2012]. The first one-stage constructed wetland in Poland was built during 1994-1996 and the scheme of such a facility can be seen on the Appendix 1. Constructed wetland wastewater treatment method involves the use of sorption processes of pollutants, chemical redox reactions and biological activity of selected plants that inhabit the marsh ecosystems. Wastewater treatment using wetlands can take place in natural or artificial conditions,

then called "wetland" and "constructed wetland" respectively. Such wastewater treatment is widely applied in many countries (Austria, Czech Republic, Denmark, Germany, Italy, Poland, Portugal, Korea, Japan, Australia etc.) Pollution removal in constructed weltand systems occurs due to the functioning of a biofilm which is formed during the flow of wastewater through the bed. Plants play an auxiliary role in the sewage treatment process. In the rhizosphere (around plant roots) oxygen is produced, while other parts of the bed are anaerobic zone and they are poorly oxygenated. Plants in the constructed wetland systems can be assessed as elements which enable constant oxygen supply from the atmosphere to the bed. Due to the aerenchyma diffusion of oxygen from the atmosphere through the leaves and reed stems allows oxygen to flow into the root zone and then into the ground bed ecosystem, where oxygen can be additionally transferred through molecular diffusion resulting from the chaotic movement of gas particles [Brix 1993]. Plants in constructed wetland systems can have the following functions: stabilizating the surface of beds and protecting them from erosive wind, excellent habitat for fauna (especially birds), excellent thermal insulation, protecting the filter material from freezing in winter, excellent conditions for the development of heterotrophic microorganisms responsible for the organic matter rotting.

Fig.1. Hybrid constructed wetland in Stare Załucze in the Polesie National Park (VF-HF)

In recent years there has been observed a tendency to build hybrid CWs consisting of two or three beds with vertical and horizontal wastewater flow [Gajewska and Obarska-Pempkowiak, 2009; Dębska et al., 2015; Jóźwiakowski et al., 2016]. According to many authors, hybrid CWs provide better conditions for biological wastewater treatment [Gajewska et al., 2004; Gajewska and Obarska- Pempkowiak, 2009; Vymazal, 2005; Masi and Martinuzzi, 2007]. There can be different types of hybrid CWs, we can combine not only different plant species but also different types of sewage flow can be implemented – with vertical and horizontal flow.

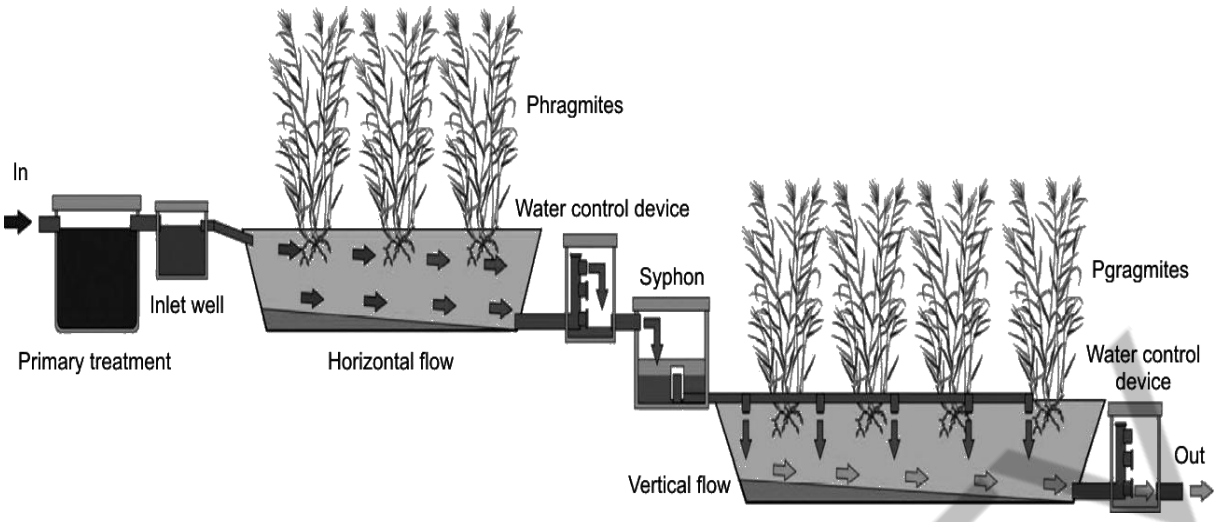

Fig.2. Scheme of hybrid constructed wetlands with HF and VF beds

So far there has been built a lot of constructed wetlands in Poland. Many researchers test different equipment and combinations of plant species in order to obtain the best efficiency of domestic wastewater treatment. One of such scientific groups which concentrate on CW systems is the Department of Environmental Engineering and Geodesy from the University of Life Sciences in Lublin. The scientists design and make studies especially on the objects located in south-eastern part of Poland, in Lublin voivodeship. The most common ones are recently the hybrid CWs located in the Roztocze National Park and in the Polesie National Park.

Fig.3. Hybrid constructed wetland

A very interesting aspect that should be mentioned is the unique shape of these CWs. For instance in Kosobudy the ground and plant beds are designed in the shape of a christmas tree, while in Stare Załucze we can observe a turtle shape wastewater treatment plant. The application of constructed wetlands in the areas of nature protection proves that this is a great solution of wastewater treatment which enables not only reliable operation and environmental care of endangered places but can also provide landscape and educational profits because of their interesting shapes and innovative methods used. A multicriterial analysis which takes the above-mentioned criteria into account shows that the use of CWs is consistent with the idea of sustainable development [Jóźwiakowski et al. 2015]. These systems fulfil all of the sustainability criteria, in particular the ecological criterion, as they ensure high efficiency of wastewater treatment with relatively small energy demand [Jóźwiakowski et al. 2019].

It has been observed by many researchers that constructed wetland enable not only high efficiency of wastewater treatment but also a reliable operation for many years. According to many authors CW systems can be a great solution for domestic wastewater treatment as they enable the elimination of many different pollutants such as: TSS, BOD_5, COD, total nitrogen, total phosphorus, heavy metals and pathogens.

Fig.4. Hybrid constructed wetland in Kosobudy in the Roztocze National Park (VF-HF-HF)

The basic element of every constructed wetland system should be an initial septic tank which ensures the elimination of the biggest pollutants during sedimentation, flotation and fermentation. Then sewage after initial purification can be easily treated while biological purification processes occurring in the ground and plant beds. About 25 years of research on the CWs in south-eastern Poland has shown that the discussed

systems provide especially high efficiency (over 80%) of biological pollutants removal, which has been expressed by the decrease of BOD_5, COD and TSS values [Jóźwiakowski et al. 2019]. The changes in the state of wastewater treated in the CW system are easily visible which is presented in the Appendix 6. Long term observations have shown that the efficiency of different pollutants removal in the hybrid constructed wetlands is bigger than in the case of one stage CW systems which can be seen. For this reason the discussed systems are suggested to be implemented not only on rural areas with dispersed housing, but especially on the protected areas, where the demands of pollutants removal are extremely tight.

On the basis of the polish experiences it can be stated that the efficiency of different pollutants removal is higher in hybrid constructed wetlands than in one-stage systems. Hybrid constructed wetlands not only resolve ecological problems about wastewater management but can also provide landscape and educational profits because of their interesting shapes and innovative methods used. Long term research on the operation of constructed wetland systems in Poland indicate that these systems can be used with great success on rural areas, especially in protected areas and valuable landscapes in Ukraine.

II. PERSPECTIVES FROM USING HYDROBIONTS AND AERATED LAGOONS

Very promising and perspective biotechnology resource for wastewater treatment are such hydrobionts as cyanobacteria. Cyanobacteria play significant role for balanced development of hydro-ecosystems, since they are the main, and sometimes the only, producers of primary organic substance in them. It is estimated today, that from 20 to 30 % of oxygen, obtained from photosynthesis in our planet, is owed to cyanobacteria. This is exactly why they played central role in alteration of air content and atmosphere structure. Cyanobacteria fix oxygen not only in soils, but in coral reefs as well as in other marine ecotopes, making nitrogen available to other organisms under conditions of different ecosystems. Cyanobacteria don't need vitamins for existence and development. They can use nitrates or ammonia as source of nitrogen and also phosphorus compounds and microadditives of such elements as ferrum, sulphur, zinc, copper, manganum, cobaltum, molybdenum etc. Most of their species are phototrophs, but some filamentous types can grow in darkness, using some carbohydrates (glucose or saccharose) as source of energy. Optimum conditions for cyanobacteria growth lay in complex of interconnected, mostly abiotic factors. The method of thickening of the aqueous suspensions of *Microcystis aeruginosa* using the coagulation-flocculation pretreatment was studied using the industrial coagulants and flocculants produced by P.P.H.U. WĘGLO-STAL (Poland). In the investigated suspension of *Microcystis aeruginosa* (without cavitational treatment, or after cavitational treatment), an appropriate reagent composition was added. Content of additives in different samples of suspension are given in Appendix 14. In order to improve the techno-economic indicators of the method researches were done using the very diluted suspensions. The mass contents of PAX-18 and PAX-XL19H coagulants in different suspensions were equal 10 ppm or 1 ppm, and the mass content of

flocculant A100 was 10 ppm or 1 ppm, if it used separately, and only 1 ppm if it used in combination with coagulants.

The results of microalgae suspensions thickening by sedimentation with preliminary coagulation and flocculation treatment with the PAX-18 and PAX-XL19H polymer coagulants, as well as the A100 flocculant are shown in Appendix 15. The numbers of the measuring cylinders correspond to the type and concentrations of the additives indicated above in the Appendix 14. Cyanobacteria biomass contains many target products that are valuable for different fields of modern bioeconomics: food, pharmaceutical and perfumery industry. Under natural conditions these bacteria massively grow for centuries as primary source of organic compounds. In our time much effort has been put in field of genetic engineering for modification of phototrophic microorganisms, especially cyanobacteria, − producers of new useful compounds (target products) that aren't synthesized in natural way. Actual direction of modern studies is also environmental biotechnology and bioenergetics that anticipate direct application of cyanobacteria large-tonnage biomass and other massive forms of hydrobionts as raw material for biofuel production (biomethane, bioethanol and biodiesel) and mineralorganic fertilizer. Production of another fuel type − biogas (biomethane) using method of anaerobic digestion of cyanobacteria (biomethanogenesis), that uncontrollably grew during summer period in reservoir water area of Dnieper waterfall. Experiments have shown, that although no universal method for harvesting and concentration of microalgae exists (it is still productive field for studies), for every particular algae species, optimal economic ways and methods can be made. After concentration, in majority of cases it was used a biomass dehydration, resulting increase its maximum term of residence. For microalgae, such ways of dehydration are used as drum, pulverizer, sublimation or solar desiccation. Extraction of lipids and pendent fatty acids from biomass is conducted directly from lyophilization biomass. For extraction can be used such dissolvents as hexane, ethanol or mixture of both hexane and ethanol, which allows to extract up to 98 % purified lipids and fatty acids. Studies have shown, that in case of damage of cellular wall of algae with help of ultrasound procession, extraction of target product increases from 4,8 % to 25,9 %. From obtained feedstock, biodiesel can be produced using traditional technology– repeated esterification of plant oils. Lipid feedstock consists from 90–98 % (weight) triglyceride and small amount of mono- and diglyceride, contains free fatty acids (1–5 %) and small amounts of phospholipids, phosphatides, carotenes, tocopherols, sulphur compounds and remnants of water.

The most popular wastewater technologies in Ukraine are the following: reverse osmosis technology; technology of chemical and biological oxidation; infiltrate knotting technology; technology of biological purification in anaerobic and aerobic medium.

Aerobic methods of biological purification of filtrates have row of undeniable advantages over anaerobic: they are flexible in using, fast include in stationary regime of work, fast accommodate to changeable composition and expanses of filtrates. Aerobic reactors are far more simpler in construction and far more cheaper than anaerobic, they are also much easier automatized and easier in exploitation.

From analysis of existing natural studies it is possible to make conclusion, that purification of infiltrates in aerobic lagoon (or simultaneously connected lagoons) is simply, low-budget and enough efficient method of pretreatment of infiltrates.

Study of the aerobic purification was conducted at plant (Appendix 16).

The plant contained from 5-litter bulb, that with volume of 4 l was filled with infiltrate. Infiltrate for studies was chosen from pound-accumulator of Lviv MSW For aeration the air was supplied to bulb with the help of laboratory compressor. With the help of regulation compressor, set on air flow tube, it was regulated air expanses on aeration and supported constant significance of this expanse throughout the whole experimental time. Experimental work was conducted in two stages.

At first stage (static) was set alteration of COD, concentrations of ammonium nitrogen, pH and concentration of dissolved oxygen under conditions of continuous aeration without allotment of pretreated infiltrate and accordingly without addition into volume `fresh`, untreated infiltrate.

At second stage (dynamic) that was conducted after obtaining maximum possible level of purification under static regime, it was modeled continuous regime of purification, that is planned to be implemented at industrial pollution control facility. Once in 24 hours from bulk it was taken certain amount of infiltrate and was poured same amount of `fresh` unpurified infiltrate. For certain proportion significance of the sample the researches were conducted for obtaining constant concentrations of ammonium nitrogen and COD. After that, the daily volume of purified and `fresh` infiltrate was substituted, that accordingly was collected and poured into aeration plant, and it was studied a process of aerobic purification in dynamic regime for another time significance of infiltrate delay in aeration zone. Once in a day an infiltrate sample from bulk for analysis and sample for addition of infiltrate were taken.

Methodology of tertiary infiltrate treatment research at PCF.

For experiments in static regime for research place a mixture of effluents with active sludge was taken. Infiltrate in quantity of 1 m^3 was selected from pound-accumulator №5 in MSW Hrybovytske landfill. In experimental aeration plant was poured mixture of effluents and active sludge and was added calculated quantity for obtaining mixtures, that met the following dissolving criteria: 10; 500; 1000; 1250; 1500. In reactor it was added mixture of effluents with active sludge till obtaining general volume in 1,64 m^3. After that samples were taken for chemical experiments and the plant was launched. Every study cycle in static regime lasted 6 hours. After finishing of air supply a sample was taken for conducting chemical experiments.

Experiments in dynamic regime were conducted at the same plant (Appendix 17) The plant contained primary settlers: primary model settler for mixture of effluents with infiltrate and primary model settler for effluents without infiltrate. During 8 daily experiments the mixture from effluents and infiltrate as equally carried to aeration plant 1. Regulations of expanses were carried with the help of circulation pump and valve. Homogeneity of the mixture was obtained with the help of aerator. After 8 hours of mixture supply from effluents with infiltrate it was modeled working process of aerotank during 16 hours without adding infiltrate.

General strategy for two-stage cultivation of landfill infiltrates

Analyzing research data it is recommended principal scheme for implementation of landfill infiltrates pretreatment technology that is illustrated. According to this scheme, infiltrates are accumulated in pound-accumulator that simultaneously serves as aerobic lagoon.

For this it is equipped with aeration system. Pound-accumulator is being screened with protective display by using well known technologies. In aerobic lagoon biological aerobic oxidation is taking place of organic contaminants and of ammonium nitrogen. Constant inflow is being realized and harvesting of infiltrates under conditions of supplement with necessary period of infiltrate residence in reactor. Infiltrate collection is being done with the help of pump station throughout set pipeline «landfill – municipal PCF» infiltrate is transferred into mixing block PCF where at given proportion it is mixed with municipal effluents and in mixture is directed to tertiary treatment at municipal PCF. For every particular case for technology implementation it is necessary to make balance calculation.

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ANALYSIS AND ASSESSMENT OF ECOLOGICAL SAFETY OF EMISSIONS FROM PRODUCTION OF CARBON PRODUCTS

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Abstract. *Enterprises producing carbon products are man-made sources of air pollution with carbon monoxide (II) and hydrocarbons. The presence of these substances in the ambient air is harmful to human health, namely, it causes diseases of the circulatory system, respiratory and nervous systems and is especially dangerous for the population of childhood. The goal of the work – to assess the risk of the impact of pollutants from emissions from an enterprise producing carbon products for the health of the population of Zaporizhzhia. Research methods: health risk assessment methodology; analytical methods for assessing the toxicity of pollutants; mathematical methods (probabilistic assessment) for calculating the levels of risk to the health of the exposed population. Work contains of 15 pages, 2 figures, 2 tables, reference with 5 scientific sources. Results of work: a list of priority pollutants has been compiled; the characteristics of the risk of air pollution from stationary sources of an enterprise producing carbon products have been established.*

The estimation of risk for population health from influence of carbon oxide and hydrocarbons waste of the carbon production enterprises is given here. After analyzing ecological emissions safety of the carbon production enterprises it was established that enterprises activity belongs to the average degree of risk and ability to get respiratory organs diseases, sight, cardiovascular and central nervous system diseases of old persons, pregnant women and children.

Keywords: *gas emissions, carbon monoxide, hydrocarbons, hazard coefficient, hazard index, risk assessment, atmosphere air.*

I. INTRODUCTION

The annual increase tendency of harmful emissions from industrial enterprises(by an average of 3-7%) is observed in Ukraine recently. Analyses show that about 10 million tons of harmful chemicals are released into the atmosphere annually; moreover, about 70% belong to the waste of stationary sources. This problem is particularly relevant to regions with a significant concentration of industrial enterprises. This fact underlines the urgency of solving the problem of health protection of population, which live in the industrially loaded territories of Ukraine [1, 2].

The safe level of ensuring air quality is one of the main tasks of state policy, that is confirmed and reflected in the latest state strategic and planning documents, in particular, in the Law of Ukraine «About sanitary and epidemiological welfare of the population» and in the Strategy of National Environmental Policy of Ukraine in the period up to 2020 (Law of Ukraine Nº 2818-VI dated December 21, 2010).

At the same time, the methodology for the public health risk assessing in these documents is considered as the most effective managing tool. It allows to characterize the probability of harmful influence on the people health and substantiate the safety of population, living in the areas located near industrial enterprises, highways or other «risk zones» as a result of actual or potential pollution of the environment, in particular, atmospheric air.

Thus, the purpose of the study is to estimate the public health risk from air pollutions produced by enterprises of carbon products.

This research work uses general procedure for the public health risk assessing (Human Health Risk Assessment), developed and recommended by the US Environmental Protection Agency. It involves four interrelated steps [3]: hazard identification, exposure assessment, dose-response assessment and risk characterization.

II. EXPERIMENTAL PART

Zaporizhzhia region is one of the loaded regions in terms of industrial potential, caused by concentration of ferrous and nonferrous metallurgy enterprises, heat and power engineering, nuclear energy, chemistry, mechanical engineering [1]. The fact that enterprises - the main polluters, are concentrated in several industrial zones located near the residential buildings of the city (about 25 thousand people live within the sanitary protection zones of the main air pollutants of the regional center) is the specific feature of Zaporizhzhia. The situation is aggravated by the location of the main industrial hub on the windward side in relation to the residential city areas, that increases their pollution. So, the air pollution forecast will allow to take into account these data when planning the activity of industrial facilities in Zaporizhzhia.

The most common pollutants in Zaporizhzhia are dust, sulfur compounds, nitrogen oxides, carbon monoxide and hydrocarbons, which are the main reasons of ecologically dependent diseases and states.

The analysis of environmental safety of pollutants emissions was carried out in the zone of the enterprise of carbon products influence, because its emissions contain CO (82%) and toxic hydrocarbons (5,5%), such as benzopyrene, benzene, styrene and phenol.

Enterprise of carbon products is the leading manufacturer in Ukraine of graphitized electrodes for electric steel-making, ore-thermal and other types of electric furnaces, carbon, electrode and anode masses for electrodes, carbon paste, carbon-lining materials (blocks) for metallurgical, machine-building, chemical and other industry complexes.

2.1 Results of the hazard identification stage

Enterprise of carbon products releases into the atmosphere 27 pollutants of 1-4 hazard classes, which have different directions of influence on public health [2]. Characteristics of scenario and route of pollutants exposure selected for conditions of the enterprise are described in Table 1. The main route of pollutants entry into the human body is the inhalation. The medium was analyzed and defined as atmospheric air.

Table 1. Characteristics of scenario and route of pollutants influence selected for the conditions of enterprise of carbon products

Part of the exposure	**Exposure characteristic**
Negative impact factor	The enterprise emissions into the atmospheric air from stationary organized sources
Influence path	Inhalation
Influence scenario	Residential area
Type of contact (by time)	Acute
The age of the exposed group	The average person (30 years)

The selection of priority pollutants which enterprise emissions contain was made taking into account the amount of waste volume in the atmospheric air and the results of their ranging according to comparative indexes of carcinogenic and non-carcinogenic danger. As a result, a list of priority pollutants was composed.

The list includes 12 chemical compounds, where benzopyrene belongs to class 1 hazards (extremely hazardous substances); nitrogen dioxide, benzene, manganese and its compounds, hydrogen sulfide, sulfur dioxide, styrene and phenol belong to class 2 hazards (highly hazardous substances); acenaphthene and suspended substances belong to class 3 hazards, naphthalene and carbon monoxide belong to class 4 hazards.

As part of the priority pollutants, 3 chemicals have a carcinogenic effect. According to the classification of the International Agency for the Study of Cancer, benzene belongs to the group of class 1 carcinogens, that is, the most dangerous for humans; benzopyrene and styrene - to the group of possible human carcinogens.

2.2 The results of the exposure assessment stage

The area of public health risks research from stationary sources of enterprise emissions (area 7×7 km) was divided by a receptor grid into 8 identical segments of 45° by rumba wind direction, starting from the north (0°). Each segment «was cut» from the center of the enterprise. Then it was defined along the borders of three industrial sites, into sectors from 500 to 3500 m with a grid step of 500 m.

Average concentrations of pollutants, the calculation of which was carried out at 56 nodes at a given receptor grid, not taking into account city's background, were offered by enterprise.

In determining the exposed population, its density at the receptor nodes and the geography of the pollution sources location were taken into account.

High population density near the industrial site of enterprise is observed at a distance of 3000 m in the north-east direction (15–19 thousand people per 1 km^2) and at the distance of 2500 m in the south-west direction (11–15 thousand people per 1 km^2). The public health risk assessment was carried out at 14 nodes of a given receptor grid in the northeast and southwest wind directions.

2.3 The results of the evaluation phase of the «dose-response»

The obtained levels data of averaged concentrations were compared with reference concentrations data to estimate the probabilistic emission influence on the health of the exposed population with the acute inhalation effect from the main pollutants of enterprise. It allowed us to estimate the risk for public health consequently. The

reference concentrations excess at 56 nodes of the receptor grid is the characteristic of manganese and its compounds, benzopyrene, naphthalene and benzene.

2.4 The stage results of public health risk characteristics

The air pollution risk characteristics from stationary sources of enterprise in the calculated nodes of the receptor grid were established. They include [2]:

- calculations of individual and total cancer risks to the health of the exposed population;
- calculations of non-carcinogenic risks in the form of hazard coefficients and hazard indexes for separate substances;
- calculations of the individual death risk from emissions of dust with particle diameter less than 10 microns.

Among the main pollutants presented in the residential area, benzopyrene, benzene and styrene are carcinogenic. The results of calculations of an individual cancer risk to public health in the nodes of the receptor grid indicate to low level of risk (level De minimas) ($ICR = 10^{-9} \div 10^{-6}$) at acute exposure for all three substances. Such risks do not require any additional measures of waste decreasing and their levels may be subjected to periodic monitoring only.

The total cancer risk in 14 nodes of the receptor grid in the northeast ($R_{sum}=2{,}25 \cdot 10^{-5}$) and southwest ($R_{sum} =1{,}87 \cdot 10^{-5}$) directions indicates on acceptable level of cancer risk ($10^{-6}<R_{sum}<10^{-4}$) at acute exposure. These levels of risk are subjected to constant monitoring.

It was calculated that benzene and benzapyrene are the main to form the total cancer risk in receptor grid nodes during acute exposure.

The hazard coefficients of calculations results in assessing the acute inhalation effects of pollutants emissions from enterprise indicate to excess safe levels (HQ > 1) in the calculated nodes of the receptor grid for the following substances:

a) in the northeast direction for:

- manganese and its compounds at a distance of 500 m (HQ = 1,036), but this is not in the residential area, therefore, the health risk is absent;
- benzopyrene at a distance of 2500 to 3500 m (HQ = 1,12 ÷ 1,23);
- phenol at a distance of 2500 to 3500 m (HQ = 1,0683 ÷ 1,2517);

b) in the south-west direction for:

- benzopyrene at a distance of 2500 to 3500 m (HQ = 1,02 ÷ 1,26);
- phenol at a distance of 3000 m (HQ = 1,12).

The results of hazard indexes calculations indicate to the presence of excess safe levels of exposure (HI> 1) of the main combined pollutants during acute inhalation exposure. They are shown in Table 2.

Table 2. Hazard Index Calculation Results

Organs / Systems	**Distance, м**	**Northeast hazard indexes**	**Southwest hazard indexes**
Respiratory system	500-3000	1,477 ÷ 2,7808	1,0627 ÷ 2,0721
Organs of vision	2500-3500	1,063 ÷ 1,31	1,12
Parenchymal organs	2500-3500	1,08 ÷ 1,32	1,13

Cardiovascular system	2500-3500	1,13 ÷ 1,36	1,17
Central nervous system	2500-3500	1,23 ÷ 1,44	0,79 ÷ 1,27
Immune system	2500-3500	1,08 ÷ 1,23	1,02 ÷ 1,26
Developmental birth defects	2500-3500	1,142 ÷ 1,286	1,1 ÷ 1,32

Hazard indexes at points of high population density (at a distance of 3000 m in the north-east direction and 3000 m in the south-west direction) are shown in Fig. 1, 2.

The values of hazard indexes for acute inhalation exposure are at an average level. As a result of it there is a risk of adverse effects in sensitive subgroups of population particularly (elderly, pregnant and children) [4, 5].

The most actual in forming hazard indexes are phenol (63,93%) and sulfur dioxide (19,9%) for respiratory system; phenol – 98,54 % for parenchymal organs, 96 % for cardiovascular system,58,36 % for central nervous system; benzopyrene – 95,74% for congenital defects of development.

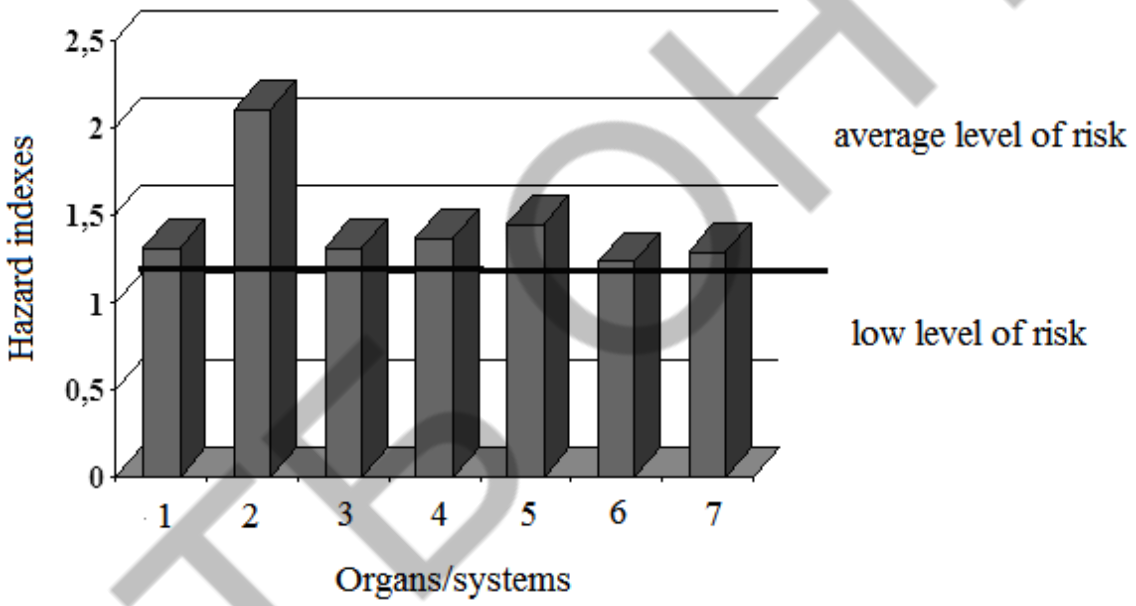

Fig. 1. Hazard indexes (HI) for public health at a point of high population density at a distance of 3000 m in the north-east direction from the center of the industrial site of enterprise:

1 – organs of vision; 2 – respiratory system; 3 – parenchymal organs; 4 – cardiovascular system; 5 – central nervous system; 6 – immune system; 7 – developmental birth defects

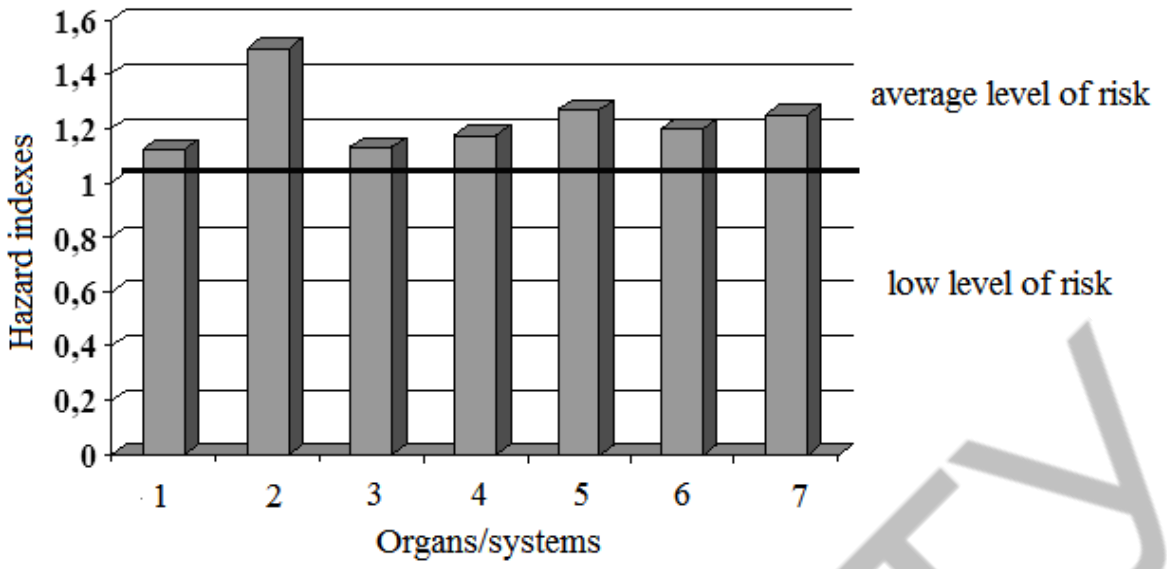

Fig. 2. Hazard indexes (HI) for public health at a point of high population density at a distance of 3000 m in the south-west direction from the center of the industrial site of enterprise:

1 – organs of vision; 2 – respiratory system; 3 – parenchymal organs; 4 – cardiovascular system; 5 – central nervous system; 6 – immune system; 7 – developmental birth defects

The hazard index formation from enterprise emissions on the citizens immune system completely depend on benzopyrene, on the citizens organs of sight - on phenol.

Monitoring and epidemiological studies conducted in many countries prove that numerous health dangerous effects, including diseases and death from respiratory and cardiovascular pathologies are caused mainly by air pollution from substances in the form of suspended solid particles (PM_{10}).

Calculations show that additional deaths are 0,07 per 1000 population during life, that corresponds to about two additional deaths at the nodes of the receptor grid.

As a result of analyzing emissions from a carbon manufacturing enterprise for environmental safety, it was found that benzene, benzopyrene, phenol and styrene are harmful substances that directly affect human health. Under the influence of these components of emissions, the probability of the formation of diseases of the respiratory, vision and parenchymal organs, cardiovascular, central nervous and immune systems, developmental birth defects in particularly sensitive subgroups of the population (elderly, pregnant and children) has been established.

III CONCLUSIONS

The following conclusions are given below as a result of the environmental emissions safety analysis from the carbon manufacturing enterprise:

- total carcinogenic risk in 14 nodes of the receptor grid in the northeast ($R_{sum} = 2{,}25 \cdot 10^{-5}$) and southwest ($R_{sum} = 1{,}87 \cdot 10^{-5}$) directions indicates a low level of cancer risk ($10^{-6} < R_{sum} < 10^{-4}$) for acute exposure, which, according to international criteria, is assessed as an acceptable level at which hygienic standards are set for the population;

- the results of calculations of hazard coefficients (HQ = 1,036÷1,2517) and hazard indexes (HI = 1,0627÷1,32) in estimation the acute inhalation effects from

production of carbon products pollutants emissions are on the average level. This level of risk does not require emergency measures to eliminate it, but cannot be considered as acceptable.

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THE USE OF BY-PRODUCTS OF CROP PRODUCTION TO STABILIZE THE BALANCE OF NUTRIENTS IN THE SOIL

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Abstract. *It is estimated that under conditions of intensive agriculture with the cultivation of winter wheat, corn, sunflower, winter rapeseed and soybeans, these crops can generate an average of 3.2-8.5 t/ha of by-products, the largest amount being from corn. With this amount of by-products, 20.24-68.60 kg/ha of nitrogen, 10.12-34.30 kg/ha of phosphorus, and 16.00-217.56 kg/ha of potassium can enter the soil. Most of the nitrogen, phosphorus and potassium will reach the soil with sunflower by-products.*

Taking into account the removal of nitrogen, phosphorus and potassium nutrients from the soil for the formation of the crop of these crops, the balance of nitrogen nutrients when all plant residues are returned to the soil will be negative - 71-114 kg/ha, phosphorus - minus 36-38 kg/ha, potassium - for wheat - plus 43 kg/ha, other crops - minus 37-182 kg/ha. The smallest balance of nitrogen in the soil will be observed after the cultivation of soybeans, phosphorus - sunflower, and the largest: for nitrogen - after the cultivation of corn, phosphorus and potassium - soybeans.

Keywords: *by-products, nutrients, balance.*

I. INTRODUCTION

Anthropogenic influence on soils causes their degradation, leads to a decrease in the productivity of agricultural lands. In Ukraine, the ecological consequences of soil degradation and deterioration of their quality have become particularly acute in the modern period due to the use of land as the only means of subsistence in conditions of survival at the expense of natural soil fertility, without compensation for its costs. High productivity of land in this case is ensured by applying high rates of mineral fertilizers and pesticides.

This leads to a merciless depletion of the natural fertility of soils, which is called degradation. Soil degradation leads to the deterioration of soil properties, fertility and quality, its contamination with chemical toxic substances, which is caused by a change in the conditions of soil formation due to the influence of natural or anthropogenic factors. Degradation of soils, and often their complete exclusion from agricultural use, occurs as a result of the processes of water and wind erosion, dehumification, decalcification, over-compaction by agricultural machinery, irrational operation of irrigation systems, which leads to flooding and waterlogging, secondary salinization and salinization of soils; due to violations of agricultural technology, overgrowth with weeds and shrubs, unbalanced application of mineral fertilizers, pollution with toxic substances, radionuclides, unregulated livestock grazing, etc.

As a result of such anthropogenic intervention, soils lose their natural stability, which leads not only to a decrease in their productivity, but also to a complete loss of soils and their removal from cultivation. The consequence of this can be not only a

decrease in the productivity of crops, but also a significant deterioration in the quality of the grown products, which not only reduces their nutrition, but also accumulates toxic substances: heavy metals, pesticides, radionuclides, salts and acids, petroleum products.

For a long time, the application of organic fertilizers in the form of manure was a factor in restoring and stabilizing the agro-ecological condition of soils, and therefore a factor in improving the quality of products grown on them. In modern conditions, due to the lack of animal husbandry, it is impossible to solve this problem by adding manure. Therefore, one of the most important ways to restore such soils can be the maximum return to the soil of the plant mass of crops that are not used for economic production and their waste. Such substances can be siderates, as well as by-products of crop production in the form of stubble, straw, stalks, tops, etc.

II. LITERATURE ANALYSIS

One of the determining factors that affects not only the fertility of the soil, but also the level of yield of agricultural crops and the quality of the products obtained, is the content of organic matter in the soil - humus. Its content in the soil depends on the amount of organic matter in the form of manure, siderates, plant root, stubble and stem residues [1].

The main sources of organic matter entering the soil for a long time were organic fertilizers. But the sharp reduction of animal husbandry in Ukraine in the 21st century led to a persistent shortage of organic fertilizers even for the simple reproduction of humus losses that were mineralized for the needs of plants [1].

Due to the lack of organic matter, the dehumification of soils and the deterioration of their agronomic properties began. Thus, according to the NSC "Institute of Soil Science and Agrochemistry named after O.N. Sokolovsky", the share of areas treated with organic fertilizers is 1.1% today. Therefore, over the past 20 years, the humus content in soils has decreased by 0.22% on average across Ukraine [2].

In addition to a sharp decrease in the content of humus in the soils of Ukraine, their impoverishment of the main mineral macroelements: nitrogen, phosphorus, potassium is observed. Over the past 15 years, the content of mobile phosphorus and exchangeable potassium has decreased by 1.2 and 1.4 mg/100 g of soil, respectively [3].

Therefore, in conditions of shortage of organic fertilizers, alternative sources of replenishment of soil organic matter, such as siderates and plant waste, should come to the fore.

A promising direction for restoring the balance of organic matter in the soil is sidereal crops. But it is often quite problematic to obtain their large biomass, because they require special preparation of the soil after harvesting the predecessor, the availability of sufficient moisture and heat for growth and development, and time before sowing the next crop in crop rotation. The main factor under such conditions is the lack of moisture in the soil for the formation of sufficient biomass of sidereal crops, therefore often sidereal crops do not give the desired effect if they are grown as post-harvest crops [4].

Another way of replenishing organic matter reserves in the soil can be the maximally complete use of the waste of the main cultivated crops in the form of straw, stalks, stubble and plant roots. Perennial grasses accumulate the largest amount of root

and harvest residues using this method, a little less - crops of continuous sowing and even less - row crops, especially sugar beets, melons, vegetables, corn for silage [5].

When wheat straw is plowed into the soil, 200 kg of humus is formed from each ton due to the use of soil nitrogen for the decomposition of cellulose by soil microorganisms. Therefore, it is advisable to prioritize by-products of grain crops with the addition of 7-10 kg of mineral nitrogen for each ton of straw. Application of 4 t/ha of straw will not only contribute to the growth of the yield of the first, but also of subsequent crops and the accumulation of about 800 kg/ha of humus in the soil [6].

The accumulation of plant residues in the soil is determined by the species composition, placement and ratio of crops in the crop rotation. By changing the ratio of the area under different plants, it is possible to increase to a certain extent the supply of fresh organic matter to the soil with plant remains.

It should be noted that plant residues contain a significant amount of nutrients that can be used by subsequent crop rotations. According to researchers, with the remains of various crops, from 27 to 60.5% of nitrogen, 18.5-51.7% of phosphorus, 16.7-48.1% of potassium, 27, 6-54% of calcium [7].

During the decomposition of root and post-harvest residues of grain crops, due to the relatively low content of nitrogen in their composition, mineralization processes prevail over humification processes, since nitrogen-free humus compounds are unstable and mineralize quite quickly. It was established that the humification coefficient for winter wheat root remains is within 0.15-0.18 (C:N = 35-40:1), for straw - about 0.10 (C:N=80:1). Due to the wide C:N ratio in straw during its decomposition, microorganisms consume mineral nitrogen from the soil. According to Kononova, the humification coefficient of organic fertilizers is 0.2-0.3 (C:N = 25-35:1). During the decomposition of straw, not only a certain amount of mineral compounds necessary for plants, but also a lot of carbon dioxide (from 25% of the total mass of straw) enters the soil. When combined with water, it forms carbonic acid, which contributes to the transfer of a certain amount of soil nutrients into a soluble form. Straw improves the air and nutrient regimes of plants [8].

The decomposition of plant residues in the soil is slow and depends on the quality of their wrapping and weather conditions. It has been established that up to 46% of straw decomposes in 2.5-4 months, up to 80% in one and a half to two years, and the rest later. When 1 kg of straw decomposes in the soil, after 3 months, about 50 g of humus is formed, and after 2 years, the growth ends, reaching a maximum value of about 90-100 g. Newly formed humic substances belong to the so-called "nutritive humus", and after 4 years, their decrease to 70 g is noted [9].

Taking into account the types of restrictions on crops grown in modern crop rotations, which are represented by winter wheat, corn, soybeans, sunflower, and winter rapeseed, it is necessary to use by-products from these crops as much as possible to replenish humus reserves in the soil.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The research was intended to study the effect on the balance of nutrients in the soil of the complete return of by-products of the main agricultural crops of intensive agriculture.

The research was conducted on the basis of the processing of materials of the State Statistics Service regarding the sown areas and yield levels of the main crops: winter wheat, corn, sunflower, winter rape and soybeans.

On the basis of reference data, an assessment of the amount of by-product accumulation by all crops in the form of their straw was carried out [10]. We also used reference data on the content of nutrients in the straw of the researched crops: nitrogen, phosphorus, potassium. Calculation methods were used to calculate the input of nutrients to the soil and the consumption of nitrogen, phosphorus and potassium nutrients for crop formation [11].

IV. RESULTS

Volumes of accumulated stubble and stem residues of agricultural crops, which can replenish the supply of organic matter of the soil in the conditions of modern intensive crop rotations, depend on the size of the main crop of grain or seeds. The ratio of the grain yield of winter wheat to the weight of its straw is 1 to 1.1; corn and rape - 1 to 1.3; sunflower - 1 to 1.9; soy - 1 to 1.4 [1, 2].

With an average winter wheat grain yield of 4 t/ha, 4.5-5 t/ha of straw accumulates in the field. This amount of straw contains 20 kg of nitrogen, 10 kg of phosphorus, 140 kg of potassium and calcium, 8-10 kg of sulfur and more than 400 g of trace elements [3].

In corn, with an average yield of its grain of 6 t/ha, 7.8 t/ha of plant residues remain with the content of 58 kg of nitrogen, 23 kg of phosphorus, 127 kg of potassium, as well as sulfur, magnesium and trace elements [3].

In post-harvest sunflower residues weighing 5.7 t/ha with a seed yield of about 3 t/ha, the nitrogen content is 80 kg, phosphorus – 40 kg, potassium – 253 kg, calcium – 87 kg and magnesium – 34 kg [3]. Straw and rape residues weighing 2-6 t/ha are equivalent to the application of 15-20 t/ha of organic fertilizers. After their mineralization, 60-65 kg/ha of nitrogen, 32-36 kg/ha of phosphorus and 55-60 kg/ha of potassium will enter the soil [4].

With the average yield of winter wheat grain in Ukraine in 2019 of 4.2 t/ha, the formation of by-products will be 4.6 t/ha. However, highly intensive rental farms in our country often achieve a winter wheat grain yield of 7.5 t/ha or more. With this grain yield, the amount of by-products of winter wheat will be 8.3 t/ha (Table 1.).

Table 1. Volumes of the formation of by-products of plants in intensive crop rotation

Culture	Ratio of grain to by-products	The average volume of education of by-products, t/ha	The maximum amount of by-product formation, t/ha
Winter wheat	1 : 1,1	4,6	8,3
Corn	1 : 1,3	8,5	15,6
Sunflower	1 : 1,9	4,9	7,6
Winter rapeseed	1 : 1,3	3,6	5,2
Soy	1 : 1,4	3,2	5,6

In 2019, the average corn yield in Ukraine was 6.5 t/ha. With such a yield of corn, each hectare of its sowing accumulates 8.5 tons of by-products. The maximum yield of corn grain in farms reaches 12.0 t/ha and more. With this yield, the accumulation of by-products from corn stalks will amount to 15.6 t/ha.

The average yield of sunflower seeds in Ukraine in 2019 was 2.6 t/ha. This allows you to accumulate 4.9 t/ha of sunflower by-products. The maximum possible yield of sunflower in farms reaches 4.0 t/ha. With this seed yield, 7.6 t/ha of stem residues can be accumulated in the field.

Winter rape provides an average seed yield of 2.8 t/ha in Ukraine. With this yield of winter rapeseed, the volume of by-product formation will be 3.6 t/ha. The maximum yield of sunflower seeds is 4.0 t/ha. With this yield, 5.2 t/ha of winter rapeseed stalk residues will be left.

Soy in 2019 provided an average seed yield in Ukraine of 2.3 t/ha. When its plant residues are plowed into the soil, each hectare of this crop will return 3.2 tons of by-products. At the maximum productivity of soybean seeds, which is characteristic of the best farms of Ukraine - 4.0 t/ha, the amount of by-products from it in the soil will be 5.6 t/ha.

Therefore, among the most common crops of intensive crop rotation in Ukraine, the largest mass of by-products at the average yield of grain and seeds is formed on corn crops - 8.5 t/ha. Sunflower will provide 42.4% less lateral mass of leaves and stems in the soil - 4.9 t/ha, winter wheat - 45.9% less - 4.6 t/ha. The smallest mass of by-products from plant residues is accumulated during the cultivation of winter rape - 3.6 t/ha and soybean - 3.2 t/ha. This is, respectively, 57.6% and 62.4% less than the return of by-products on corn crops.

According to reference data, winter rapeseed has the highest nitrogen content in by-products of agricultural crops - 16.3 kg/t, sunflower - by 14.1% less, soybean - by 26.4%, corn - by 54.6%, wheat winter - by 73.0% less (Table 2). The by-product of winter rape also has the highest phosphorus content - 9.0 kg/t, which is 22.2% more than the by-product of sunflower, 60.0% - than soybean, 67.8% - than corn and 75.6% more than winter wheat. Sunflower by-products have the highest potassium content - 44.4 kg/t. This is 30.0% more than winter wheat, 63.3% more than corn, 66.3% more than winter rapeseed and 88.7% more than soybeans.

Table 2. The content of the main macroelements in by-products of plants, kg/t

Culture	N	P	K
Winter wheat	4,4	2,2	31,1
Corn	7,4	2,9	16,3
Sunflower	14,0	7,0	44,4
Winter rapeseed	16,3	9,0	15,0
Soy	12,0	3,6	5,0

Therefore, the highest content of nitrogen and phosphorus is contained in the by-products of winter rapeseed, and the lowest in winter wheat; the highest potassium content is found in sunflower byproducts, and the lowest in soybeans.

At the average yield of grain and seeds of field crops, established by statistical data, when crop residues are plowed, the most nitrogen will enter the soil when growing sunflowers - 68.6 kg/ha. This is 14.5% more than when plowing by-products of winter rape, 8.3% more than corn, 44.0% more than soybeans [5, 6, 7] (Table 3.).

Table 3. Accumulation volumes of the main macronutrients in the soil during plowing of plant residues and by-products of plants, kg/ha

Culture	**It will enter the soil due to crop cultivation technologies**					
	traditional			**intensive**		
	N	**P**	**K**	**N**	**P**	**K**
Winter wheat	20,24	10,12	143,06	36,52	18,26	258,13
Corn	62,90	24,65	138,55	115,44	45,24	254,28
Sunflower	68,60	34,30	217,56	106,40	53,20	337,44
Winter rapeseed	58,68	32,40	54,00	84,76	46,80	78,00
Soy	38,40	11,52	16,00	67,20	20,16	28,00

The most phosphorus will enter the soil when plowing sunflower by-products - 34.3 kg/ha, which was 5.5% more than when wrapping plant residues of winter rape, by 28.1% - than with corn, by 66.4% - than when plowing soybeans and by 70.5% more - than when plowing plant residues of winter wheat.

After the cultivation of sunflower, the most potassium accumulates in the soil - 217.6 kg/ha, which is 34.2% more than after wrapping plant residues of winter wheat in the soil, 36.3% - than after corn, 75.1% - than after winter rapeseed and by 92.6% more than after wrapping soybean plant residues in the soil.

Therefore, the most nitrogen, phosphorus and potassium nutrients under traditional cultivation technologies will enter the soil with post-harvest sunflower residues, and under intensive cultivation technologies - nitrogen - with post-harvest corn residues, phosphorus and potassium - with sunflower residues. The least accumulation of nitrogen and phosphorus will be observed from the post-harvest remains of winter wheat, and potassium - from the post-harvest remains of soybeans.

When wrapping plant residues, it is important to determine the proportion of nutrients returning to the soil. For this, it is necessary to establish the removal of nutrients by the main crops of modern crop rotation for the formation of 1 ton of grain or seeds.

Soybean carries the most nitrogen - 100 kg/t, and the least - corn - 27 kg/t. However, soybean belongs to leguminous crops, in which part of the nitrogen is compensated by symbiotic nitrogen fixation, therefore, among the crops that do not fix nitrogen, sunflower produces the most for the formation of 1 ton of seeds - 55 kg/t (table 4.).

Table 4. Removal of nutrients from the soil by 1 ton of grain and seeds of the main crops of intensive crop rotation, kg/t

Culture	N	P	K
Winter wheat	30	12	24
Corn	27	11	28
Sunflower	65	27	155
Winter rapeseed	55	30	33
Soy	100	31	36

Soybean and winter rape consume the most phosphorus for the formation of 1 ton of crop - 30-31 kg, and the least - corn and winter wheat - 11-12 kg/t. Sunflower needs the most phosphorus – 155 kg/t, and winter wheat needs the least – 24 kg/t.

According to the traditional technology of growing agricultural crops with an average level of productivity, soybean consumes the most nitrogen from the soil - 229 kg/ha, and among non-nitrogen fixed crops - corn - 177 kg/ha and sunflower - 168 kg/ha. Winter wheat consumes the least amount of nitrogen - 126 kg/ha (Table 5).

The most phosphorus is removed from the soil by winter rape - 83 kg/ha, and the least - by winter wheat - 50 kg/ha. The most potassium is consumed by sunflower - 400 kg/ha, and the least by soybean - 82 kg/ha.

Table 5. Removal of nutrients from the soil by the yield of the main crops, kg/ha

Culture	It will enter the soil due to crop cultivation technologies					
	traditional			intensive		
	N	P	K	N	P	K
Winter wheat	126	50	100	226	91	181
Corn	177	72	183	324	132	336
Sunflower	168	70	400	260	108	620
Winter rapeseed	152	83	91	220	120	132
Soy	229	69	82	400	124	144

According to traditional technologies of cultivation of the main agricultural crops of modern crop rotation, the balance of nitrogen in the soil between the volume of removal by crops and its return with by-products of plants is negative. The most amount of nitrogen is lost in the sowing of corn - 114 kg/ha, and the least - in the sowing of soybeans due to its symbiotic nitrogen fixation - 71 kg/ha, and among other crops - in the sowing of winter rapeseed - 93 kg/ha and sunflower - 99 kg/ha (table 6.).

Table 6. The balance of nutrients in the soil for the full return of by-products during the cultivation of the main agricultural crops

Culture	It will enter the soil due to crop cultivation technologies					
	traditional			intensive		
	N	P	K	N	P	K
Winter wheat	-106	-40	43	-189	-73	77
Corn	-114	-47	-44	-209	-87	-82
Sunflower	-99	-36	-182	-154	-55	-283
Winter rapeseed	-93	-51	-37	-135	-73	-54
Soy	-71	-58	-66	-213	-104	-116

Under intensive technologies of cultivation of the main ones among agricultural crops, soybeans have the largest negative soil nitrogen balance - minus 213 kg/ha and corn - minus 209 kg/ha, and winter rapeseed has the smallest - minus 135 kg/ha.

The balance of phosphorus under the traditional technology of growing crops in the soil is negative. The greatest phosphorus deficit is observed in soybean crops - minus 58 kg/ha and winter rapeseed - minus 51 kg/ha, and the smallest - in sunflower crops - minus 36 kg/ha.

Under intensive cultivation technologies, the balance of phosphorus in the soil is more negative. It was the largest on soybean crops - minus 104 kg/ha, the smallest - on sunflower crops - minus 55 kg/ha.

According to traditional technologies of growing agricultural crops, a positive balance of potassium in the soil when plowing plant residues is observed when growing winter wheat - plus 43 kg/ha. For the rest of the crops, the balance of potassium is negative, the largest – when growing sunflowers – minus 182 kg/ha.

Under intensive cultivation technologies, the trend of potassium balance in the soil is maintained with a plus in winter wheat crops of 77 kg/ha and a minus in sunflower crops - 283 kg/ha.

In this way, it was established that under traditional crop cultivation technologies, the share of returned nitrogen nutrients relative to their removal from the soil for crop formation in winter wheat is 16%, corn - 36%, sunflower - 41%, winter rapeseed - 39%, soybean - 60%, 4% Under intensive technologies of growing winter wheat, winter rapeseed and sunflower, the share of nitrogen nutrients returned to the soil with post-harvest residues did not change, corn - increased by 29%, soybeans - decreased by 18%.

The share of winter wheat phosphorus nutrients returned with post-harvest residues under traditional crop cultivation technologies was 20%, corn – 34%, sunflower – 49%, winter rapeseed – 39%, soybean – 17%. Under intensive technologies, the share of phosphorus return for the cultivation of all crops did not change. The share of returned potassium nutrients under traditional technologies during the cultivation of winter wheat was 143%, corn - 76%, sunflower - 54%, winter rapeseed - 59%, soybean - 20%. For intensive technologies, the values are similar.

V. CONCLUSIONS

1. In the conditions of modern crop rotations with a limited set of crops, the most organic mass of post-harvest corn residues will enter the soil - 8.5-15.6 t/ha. However, the greatest accumulation of nitrogen in the soil will be observed when by-products of corn and sunflower are plowed - 62.9-115.4 t/ha; phosphorus and potassium - when plowing sunflower - 34.3-53.2 t/ha and 217.6-337.4 t/ha, respectively.

2. In the conditions of intensive agriculture with the cultivation of winter wheat, corn, sunflower, winter rapeseed and soybeans, these crops can generate an average of 3.2-8.5 t/ha of by-products, the largest amount is from corn. With this amount of by-products, 20.24-68.60 kg/ha of nitrogen, 10.12-34.30 kg/ha of phosphorus, and 16.00-217.56 kg/ha of potassium can enter the soil. Most of the nitrogen, phosphorus and potassium will reach the soil with sunflower by-products.

3. Taking into account the removal of nitrogen, phosphorus and potassium nutrients from the soil for the formation of the crop of these crops, the balance of nitrogen nutrients when all plant residues are returned to the soil will be negative - 71-114 kg/ha, phosphorus - minus 36-38 kg/ha, potassium - for wheat - plus 43 kg/ha for other crops - minus 37-182 kg/ha. The smallest balance of nitrogen in the soil will be observed after the cultivation of soybeans, phosphorus - sunflower, and the largest: for nitrogen - after the cultivation of corn, phosphorus and potassium - soybeans.

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PLASTIC WASTE AS A SOURCE OF FINANCIAL AID TO THE ARMED FORCES OF UKRAINE

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Abstract. *The consequences of the military aggression of the Russian Federation require Ukraine to find new ways to protect the environment and support the Armed Forces of Ukraine (AFU). One of the aspects that can connect these two, at first glance, unrelated areas is the use of resource-valuable components of municipal solid waste (MWS) as a source of financial support for the Armed Forces. The world is actively studying the issue of environmental pollution with plastic waste, one of the most common in Ukraine being polyethylene (34% of all plastic). The «City of the Future» public organization in partnership with the Odessa State Environmental University launched the «Plastic Saves Life» project, within the framework of which the collection of HDPE plastic lids for the purchase of an ambulance for the Armed Forces was initiated. It was found that HDPE is one of the most liquid types of secondary raw materials in Ukraine, and its collection in 9 months allowed to cover 70% of the cost of the equipped ambulance. The implementation of the «Plastic Saves Life» project is a vivid example of the fact that waste, in particular - plastic, can become a powerful source of financing for the Armed Forces.*

Keywords: *HDPE, microplastic, sorting, plastic saves lives, Armed Forces of Ukraine*

I. INTRODUCTION

During the war, the issue of proper management of the resource-valuable components of municipal solid waste (MSW) became particularly acute, which is connected simultaneously with several factors: 1) actualization of the issue of proper management of solid waste in the context of joining the EU; 2) minimization of the impact of solid waste on the environment; 3) the possibility of using municipal solid waste as an additional source of funding for certain areas, in particular - the Armed Forces of Ukraine; 4) the possibility of using waste for Ukraine's energy independence. One of the most common types of waste that is actively sorted in the world is plastic. The reason for this is its negative impact on the environment in the form of both primary plastic and microplastic. That is why, in the course of work, members and volunteers of the public organization "City of the Future" united, at first glance, incompatible aspects - environmental protection and assistance to the Armed Forces of Ukraine - and implemented the "Plastic Saves Life" project related to the use of the second type plastic (HDPE) as one of the most economically attractive resource-valuable solid waste fractions. The purpose of the work is to assess the economic efficiency of the collection of HDPE on the example of the collection of funds for an ambulance for the needs of the Armed Forces.

II. LITERATURE ANALYSIS

In Ukraine, in 2021, more than 51 million m3 of solid household waste (MSW) was generated, or more than 10 million tons, which are buried in 6,000 landfills and landfills with a total area of almost 9,000 hectares. From the total solid waste flow, about 7.64% of household waste was processed and disposed of, of which: 1.14% was incinerated, and 6.5% of household waste went to collection points for secondary raw materials and waste processing lines [1]. At the same time, it is worth noting that solid waste is a source of a significant amount of secondary material resources (SRM), which, with proper organization of the waste management system, can become a source of financial support for Ukraine, which is especially relevant during the war.

Special attention is paid in the world to the issue of proper handling of plastic waste, the average content of which in MSW is 12.9% [2]. Plastic products have a number of desirable properties, including high plasticity and durability, as well as relatively low cost. By 2019, global annual production of plastics and plastic products reached 368 million metric tons [3]. These plastics are gradually destroyed mainly under the influence of ultraviolet radiation, and weathering cannot decompose polymers, but breaks them into smaller fragments [4]. Long-term accumulation of this plastic can have consequences for terrestrial and marine ecosystems. Fragments of microplastics (MP) with a diameter of less than 5 mm are conditionally divided into primary and secondary MP. Primary MPs are MPs that are intentionally produced for various purposes, such as shampoo, toothpaste, and other everyday items, while secondary MPs are produced during the physical and chemical degradation of larger products [5].

MPs are widely distributed in the environment, found in soil and aquatic ecosystems, including seafood. Sources of MSs include soil amendments from compost and sewage sludge, irrigation, littering, and atmospheric precipitation. Compared to the oceans, terrestrial ecosystems and soil are more susceptible to plastic pollution. According to current estimates, the amount of plastic released into the terrestrial ecosystem each year is 4–23 times the amount of marine plastic, which is why the US bans microbeads in cosmetics due to health concerns [6].

Humans can inhale up to 272 MPs of particulate matter from the indoor environment each day, and these dense particles settle when they reach the lungs, where they are phagocytosed by macrophages that enter the blood and lymphatic systems. Despite the relatively high exposure through air, food and drinking water are the main sources of human exposure of 39,000 to 52,000 particles per year. The scheme of irradiation of the human body with microplastics is shown in Fig. 1.

According to [7], polyethylene (PE) in the total flow of plastic waste makes up 34%. It is worth noting that from is divided into HDPE and LDPE, but there are no data on the ratio of these types in the total flow of PE. However, taking into account the fact that PE is the largest plastic by mass in the general solid waste stream, it can be concluded that minimizing the amount of this type of plastic entering the environment is a priority.

It is worth noting that plastic is not only a source of environmental pollution, but also a valuable secondary material resource (SMR), which can be a source of financial support for Ukraine during the war. That is why in our work we have combined, at first

glance, incompatible aspects: environmental protection and assistance to the Armed Forces of Ukraine.

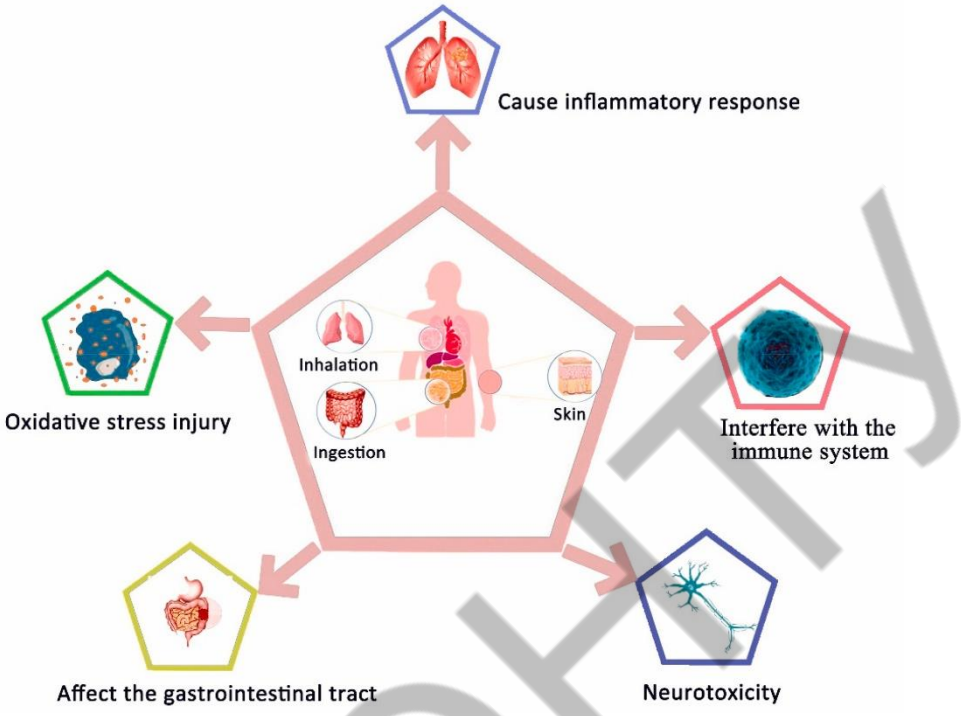

Figure 1 – Human exposure to MPs through inhalation, ingestion and skin contact [6]

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The object of study is HDPE collection on the territory of Ukraine; the subject of study is HDPE plastic as a source of funding for the purchase of an ambulance for the Armed Forces. The enterprise that sells plastic within the framework of the project is "Vtorma", Odesa [8]. The goal of the project is to collect $5,000, which will be used to purchase an ambulance for the Armed Forces.

Methods: comparative, cartographic, descriptive, generalizing, analytical, theoretical, classification, weighting.

IV. RESULTS

The implementation of the project had several stages:

1. Selection of a liquid type of secondary raw materials. At this stage, members of the City of the Future public organization analyzed the secondary raw materials market in Odesa and found that the vast majority of sorted waste in Odesa goes to VTORMA LLC. That is why we analyzed the prices of types of secondary raw materials and chose the most profitable fraction for large-scale collection. A comparative table of the most common types of recycled materials accepted by VTORMA LLC is shown in Table 1.

Based on the information in Table 1, we selected a color-sorted HDPE stream for collection in Step 1.

Table 1 – Disadvantages and advantages of the sale of various fractions of secondary raw materials during the war (according to the rates of VTORMA)

№	Type of secondary raw materials	Price UAH/kg	The main advantages for collecting	The main disadvantages for the collection
1	Wastepaper	4	easy to sort, large mass in relation to the general flow of solid waste, mostly clean	requires many months at collection points and significant transportation costs
2	Glass, broken glass is mixed	0.6	one of the most common types of raw materials collected by residents	requires a lot of money and special handling at collection points, significant transportation costs, low financial equivalent
3	Aluminum can	15	high resource cost	insufficient quality of raw materials due to contamination with organic residues, large volume of cans
4	Iron can, scrap metal	1.5	ease and sorting in everyday life, provided there is a magnet	low cost, the need for this type of raw material for the production of trench candles for the Armed Forces
5	PET bottle	6	a significant number of used bottles in the household	needs many months at collection points and reduction of bottle volume before delivery by pressing
6	HDPE covers (general flow)	5	a significant number of used bottles in the household, easy to sort, almost always clean	the small weight of one cap, the need for a large-scale collection
7	HDPE covers (sorted flow)	14*	High cost, presence of a consumer of this resource in Ukraine, a significant number of used bottles in the household, ease of sorting, almost always clean	the small weight of one cap, the need for large-scale collection, the need to organize the sorting of caps by color

** Note: the price of HDPE sorted by color is set by LLC VTORMA at 11 UAH/kg, but for sale to the needs of the Armed Forces, we agreed on a price of 14 UAH/kg*

2. Organization and operation of stationary points for plastic covers receiving. For the quick collection of plastic, we engaged public catering establishments in Odesa as stationary reception points. However, since the information about the project spread quite actively, we organized stationary locations for accepting plastic in 7 more cities of Ukraine. For 8 months, collection was carried out at these points, the results of which are presented in Fig. 2.

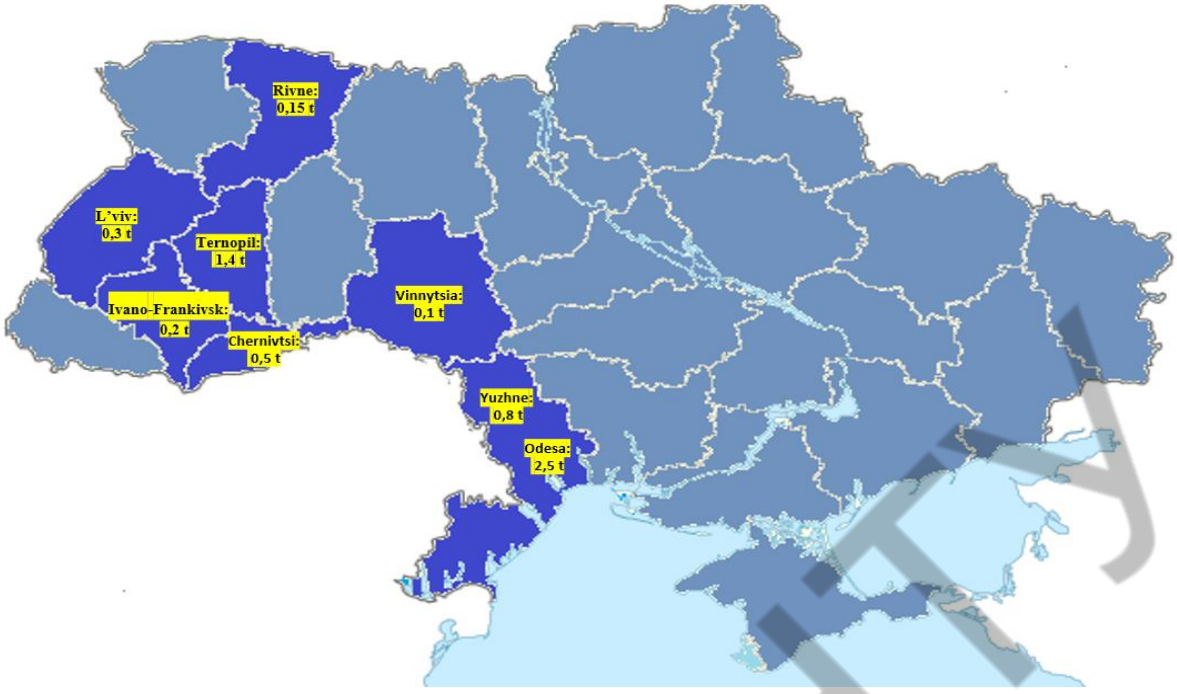

Figure 2 – The localization of stationary points for plastic covers receiving on the map of Ukraine

It is worth noting that the largest masses were collected in Odesa and Ternopil, as well as in Yuzhne, where the population is much smaller than in large cities, which proves the dependence of collection efficiency not only on the population of the city, but also on quality of collection organization.

3. Organization of receiving covers by post. All caps collected within the framework of the project (except Odesa) were transported to Odesa using the services of the Nova Poshta company, which provided free transportation of this type of raw material for our project, covering the most valuable part of the project. In addition to the work of stationary points, residents of Ukraine could hand over their lids to us for free by new mail (parcels from 5 kg), which made it possible to attract more than 40 settlements to the collection.

4. Sorting caps by color. In order to increase the cost of plastic, the sorting of caps by color groups became a necessary condition, the details of which are given in Table 2:

Table 2 – Classification of HDPE plastic waste according to the color principle

Plastic group	Colors included in this group
Group 1	White, transparent
Group 2	Red, pink
Group 3	Blue, light blue, purple
Group 4	Green, dark brown, light green
Group 5	Yellow, orange
Group 6	Black

It is worth noting that black HDPE is accepted at a cost of 5 UAH/kg. Plastic sorting took place in premises provided to us by our partners: Odesa State

Environmental University, where the bulk of the lids were stored; NGO "Common Goal", which provided its office for sorting lids. Thanks to the participation of volunteers, 100% of the entire HDPE stream was sorted. According to approximate estimates, the percentage ratio of HDPE colors has the following form (Fig. 3):

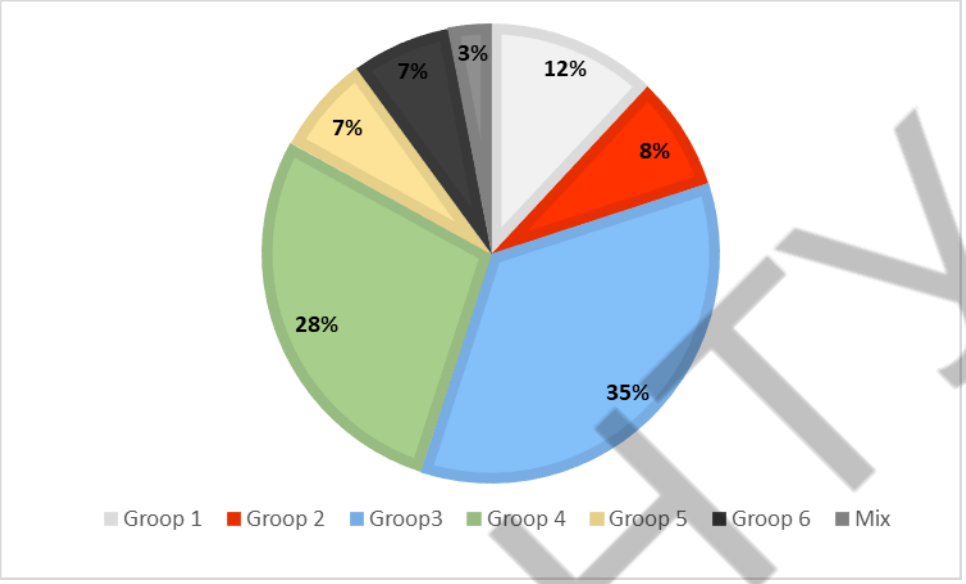

Figure 3 – Percentage of plastic covers colors in the whole mass of plastic

5. Realization of covers and purchase of an ambulance. Since an urgent request for the purchase of an ambulance was received, we were notified ahead of time of the end of the collection and the accumulated plastic was sold, which made it possible to cover 70% of the cost of the car. 30% was raised from other sources. Thus, it has been proven that environmental projects related to the collection of secondary raw materials can significantly help the Armed Forces during the war.

V. CONCLUSIONS

During the work, the following conclusions were made:

- Plastic waste is one of the most widespread of the general solid waste stream, which requires emphasis on minimizing its generation;
- Plastic waste of the HDPE type is an important resource-valuable component of solid waste, which can be used as an additional tool for financial support of the Armed Forces;
- the general flow of HDPE can be made more liquid with the help of color sorting, almost equating it in terms of financial efficiency to aluminum waste;
- the collection of plastic by the public organization "City of the Future" in 9 months made it possible to collect 70% of the amount for an ambulance for the Armed Forces. However, the industrial scale of collection could cover much more significant needs of the Armed Forces;
- the implementation of such projects effectively solves both the issue of environmental protection and financial assistance to the Armed Forces of Ukraine and victims during the war.

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ASSESSMENT OF THE ECOLOGICAL STATE OF GREEN SPACES IN THE CITY OF ALMATY

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Abstract. *The methods of making an inventory of green spaces in cities and settlements of the Republic of Kazakhstan, developed on the basis of standard documents, are studied; the results of assessment of qualitative and quantitative characteristics of green spaces in Almaty on the example of Bostandyk and Medeu districts are given; the recommendations on maintenance and protection of green spaces in the city are offered.*

Keywords: *ecological condition, green spaces, inventory, dendrochronology, plantation protection*

INTRODUCTION

Relevance of the topic. The urban ecosystem suffers from the manifold impacts of human activity. As the planet's lungs, providers of oxygen and living filters for capturing gases and dust, the city's green vegetation itself is under threat of weakening. And yet human health is directly linked to the state of the environment. There have been cases where falling trees have caused direct harm to city dwellers. In this regard, an assessment of the qualitative and quantitative condition of green spaces will make it possible to take economic measures that will help to prevent negative consequences.

The purpose of work: to assess the qualitative and quantitative condition of green spaces in Almaty.

The main idea of the study. When counting the quantitative condition of green spaces, the non-settlement area of the city should be separated out and should not be taken into account on the same level as the residential area.

Objectives of the work:

1. Study of methods of conducting an inventory of green spaces of cities and settlements of the Republic of Kazakhstan, in accordance with regulatory documents.
2. Assessment of the qualitative and quantitative characteristics of green spaces in Almaty on the example of Bostandyk and Medeu districts.
3. Development of recommendations on the maintenance and protection of green spaces in Almaty

Research methods: inventory of green spaces in populated areas of the Republic of Kazakhstan.

Objects of the study: tree and shrub plantations growing on the territory of Almaty city.

Subject of the study: states of tree and shrub plantations growing on the territory of Almaty city.

Scientific novelty of the study. The author proposes to apply the methods of dendrochronology to the survey of plantations in an urban environment.

Practical significance of the work. The theoretical significance of the study is

to clarify the quantitative and qualitative condition of green spaces in Bostandyk and Medeu districts of Almaty. The practical significance of the work lies in the assignment of economic activities depending on the qualitative state of green spaces.

SECTION 1. METHOD OF ASSESSING THE ECOLOGICAL STATE OF GREEN SPACES AND METHODS OFTHEIR INVENTORY

1.1. Assessment of the ecological state of green spaces

The city of Almaty is the largest city in Kazakhstan and is considered to be its economic centre, ranking first in terms of GRP per capita. The city is divided into 8 administrative districts: Alatau, Almalin, Auezov, Bostandyk, Zhetysu, Medeu, Nauryzbai, Turksib. The total area of Almaty is 682 km2. The city is located in a depression, due to which surface inversions are formed which lead to accumulation of exhaust gases of motor transport, emissions of thermal power plants and other industrial enterprises in the surface layer of the atmosphere. The formation of smog, which can be observed at any time of the year, is common in the city. The amount of weak wind flows up to 1 m/s in summer time is about 70 percent, in winter time this figure rises up to 80 percent. The average annual wind speed is 1.7 m/s. There is a mountain-valley circulation of air flows in a meridional direction from the foothills of the mountains at a distance of 20 km. However, it should be noted that there is intensive construction of high-rise buildings in this area, which significantly reduces the access of mountain air masses[1]. As a result of poor ventilation and low aeration, atmospheric pollution has a negative effect on the health of the population. Among Kazakhstan's cities, Almaty ranks first in terms of primary respiratory disease incidence.

The level of atmospheric air pollution by the ISA5 for the city of Almaty is considered to be "elevated"[2]. High levels of atmospheric pollutants, substances alien to the atmosphere, xenobiotics, gases, heavy metals are emitted into the environment in large volumes every day. Some of them are dispersed in the air and carried away for many kilometres. The other part having risen into the air gets into human respiratory organs, pollutes rivers and lakes, vegetation and soil and causes enormous pressure on the city ecosystem. To improve ecological situation in the city one of the effective measures is to increase the area of "green" territories. There are currently 2.352 million trees in the city. The actual green fund is 1.8 million (77 percent), of which 539 thousand plantings (23 percent) are weakened [3]

Inventory and survey of green areas were conducted in the territory of Bostandyk and Medeu districts of Almaty (Figure 1). The works were carried out in accordance with the "Procedure of passportization and inventory of parks, public gardens and green areas of Almaty city" approved by the Department of PRiP of Almaty city in 2017.

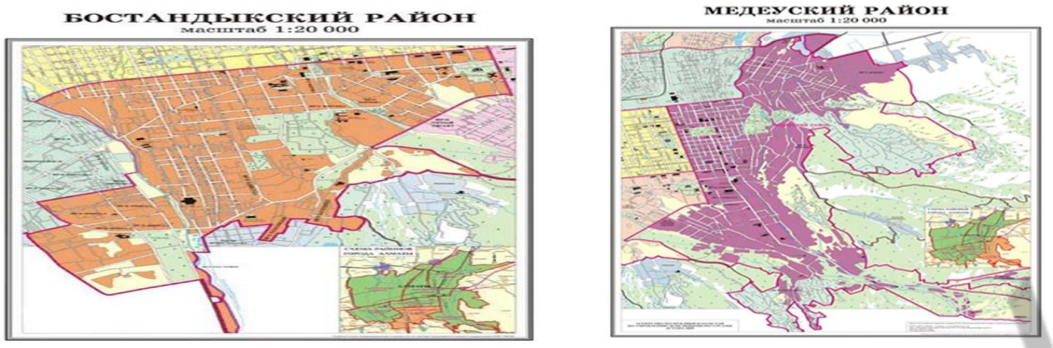

Figure 1. Schematic maps of the surveyed areas

1.2 Methodology for green space inventory

Based on the "Methodology for Inventory of Green Space in Cities and Towns of the Republic of Kazakhstan" in 2018-2019, the working group of the Almaty branch of the Kazakh Institute of Forestry and Agroforestry LLP carried out an inventory of green spaces in Bostandyk and Medeu districts to determine the qualitative and quantitative condition, species composition, tree and shrub vegetation, create a data bank and maps of planting location, to improve the efficiency of management of green spaces in the city of Almaty [4].

The client for this work was the Akimat of the city of Almaty, Department of Green Economy.

The main objectives of a green space inventory are:

- Obtaining reliable data on the number of green spaces in a populated area.
- Determine their qualitative, sanitary and hygienic condition.
- Identify the species composition of tree and shrub vegetation.
- Designate management measures according to the condition of the green vegetation.

To carry out the green space inventory work, the following were used:

- "tree and shrub species identifier" to determine species composition;
- a measuring fork for determining the diameter of trees,
- an altimeter to determine the height of trees,
- map of the site map showing the road and trail network, buildings and structures;
- an age drill to determine age.

In carrying out the inventory work, knowledge of tree and shrub species, the ability to visually identify the species composition of trees and shrubs, and the ability to prescribe management measures according to the sanitary condition of the trees and shrubs were indispensable.

The territory of each district (Bostandyk, Medeu) was conditionally divided into quarters, which were given serial numbers. Quarterly maps were issued to tax collectors. To each object of taxation (trees and bushes) we assigned a number of a planting, based on the route of the movement, and put it on the map accordingly. At the same time we filled in the taxation description sheet, where the information about

each taxation unit was entered. We entered the number of the planting patch on the taxation description sheet according to the number on the map. The name of the plant was indicated according to its species. The age of trees on deciduous trees and shrubs was indicated according to a five-year scale (5, 10, 15 etc.), on conifers according to a ten-year scale (10, 20, 30 etc.) [5].

The age of trees and shrubs is usually determined with an age drill using the annual rings of the stand and visually according to the diameter of the trees and shrubs. The age was mainly determined visually by stand diameter. Diameter was determined using a measuring fork, at a height of 1.3 m (at breast level), by 2 cm grading up to 16 cm and over 16 cm by 4 cm grading. The height of trees and shrubs was determined with an altimeter and visually. The sanitary condition of the site was established visually, by external biomorphological signs.

In addition, the qualitative condition of the object was determined (QCO) according to five categories [6]. QCO 1 - "healthy", without signs of weakening, with normal development and without damage, i.e. normal crown development and high ornamental value, intensive shoot growth, pests and diseases are absent (in winter and early spring period is not determined). In terms of age, these are mainly young and middle-aged stands. Figure 2a below shows an illustration of a healthy stand according to QCO 1.

QCO 2 - "Weakened", this includes stands with minor damage or with one-sided crown branching, medium ornamental value, up to 10% dry limbs, weak decline, i.e. less than a leaf plate or needles, 25% damage by pests and diseases (not identified in winter). These are mostly mature stands. Figure 2b below shows an illustration of a "weakened" tree according to QCO 2.

QCO 3 'Withering' trees, here very advanced branch die-off (more than 50%) pest and disease damage to the site. These are generally mature and overmature stands (Figure 2c).

QCO 4 'Deadwood', a tree that is more than 90 per cent dead or massively infested by pests. It is common to refer to QCO 4 as current year deadwood (Figure 2d).

QCO 5-6 - Trees that pose a risk to human economic activity and to the life and health of the population. Trees with an angle of inclination greater than 45 degrees and located less than 5 m from buildings and structures that cannot be left because of the present danger (Figure 2e).

a b c d e

Figure 2. Trees according to the qualitative state of the objekt: a - a 'healthy' tree, b - 'weakened', c - 'withering', d - "deadwood", e - "emergency" tree

According to the qualitative condition of the trees and shrubs, the following types of management measures are scheduled: "Maintenance work" is planned for "healthy" trees. Above-ground care, pruning, fertilizing and watering are applied. "Sanitary pruning" is assigned to "weakened" trees. Dry or dangerous branches are cut off. "Sanitary cutting" is assigned to trees in QCO 5 and QCO 6 state.

SECTION 2. QUALITATIVE AND QUANTITATIVE STATE OF GREEN SPACES IN ALMATY

2.1 Assessment of the quantitative and qualitative state of green spaces in Bostandyk district of Almaty

The survey of the area revealed the following: a total of 359770 trees of deciduous, coniferous and shrub species were surveyed. The following are summaries of the inventory results: distribution of stands by species composition, age, height, quality condition and management measures [7].

The species composition of the stands was mainly indicated by genus and species affiliation. The total number of trees in the plot was determined by eyeballing and entered in the logbook. There was a tolerance of ±10% for the species composition of plantations for each component. Table 1 below shows the species distribution of the stands.

Table 1 Distribution of plantations by species

№	Types and indicators of green spaces	Quantity, pcs.	Interest
1	Conifers	45415	12,62
2	Deciduous	266964	74,20
3	Shrubs	47391	13,18
Total		359770	100,0

In addition, the length of the hedge is 5,070 linear metres.

In Bostandyk rayon young stands are: 168858 pcs, medium-aged - 133503 pcs, mature - 27715 pcs, mature - 21282 pcs, overmature - 8412 pcs, of them presented before 10 years - 60113 pcs; before 20 years - 123629 pcs; 21-40 years - 98701 pcs; 41-60 years - 59540 pcs; and over 60 years - 17787 pcs. The age of trees and shrubs was determined on site by means of an age drill and by cutting, as well as visually by a combination of several features: the size of annual growth, condition and shape of the trunk, bark, branches, the crown as a whole and other indicators. Young trees include elms, maples, ash trees, oaks, which are up to 20 years old. Average age includes all above mentioned tree species, except for oak - from 21 to 40 years, and for oak - from 21 to 50 years. This gradation is given in Table 2

Table 2 Informative grading by age class

	Age class	Age groups - age class, (years)				
Breed composition		Youngsters	Middle-aged	Mature	Ripe	Overmature
Conifers						
Pine, spruce	20	I-II (1-40)	III-V (41-100)	VI (101-120)	VII (121-140)	VIII and v. (141 and v.)
Thuja, Biota	20	I-II (1-40)	III (41-60)	IV (61-80)	V (81-100)	VI and v. (101 and v.)
Juniper	20	I (1-20)	II (21-40)	III (41-60)	IV 61-80)	V and Art (81 and Art.)

Continuation of the table. 2

Deciduous						
Walnut	20	I-II (1-40)	III-IV (41-80)	V (81-100)	VI (101-120)	VII and v. (121 and v.)
Oak, Birch, Lime, Chestnut	10	I-II (1-20)	III-V (21-50)	VI (51-60)	VII (61-70)	VIII and v. (71 and v.)
Maple, Ash, Willow, Elm	10	I-II (1-20)	III-IV (21-40)	V (41-50)	VI (51-60)	VII and v. (61 and v.)
Aspen, Poplar, Acacia, Gladysia,	10	I-II (1-20)	III (21-30)	IV (31-40)	V (41-50)	VI and v. (51 and v.)
Loch	10	I-II (1-10)	II (up to 20)	III (21-30)	IV (31-40)	V and v. (41 and v.)
Shrubs						
Shrubs	5	I-II (1-10)	III (11-15)	IV (16-20)	V (21-25)	VI and v. (26 and v.)
Other shrubs	2	I-II (1-4)	III (5-6)	IV (7-8)	V (9-10)	VI and v. (11 and v.)
Talniki	1	I-II (1-2)	III (3)	IV (4)	V (5)	VI and v. (6 and v.)

The height distribution of the plantations is shown in Table 3. The heights are determined by a height gauge as well as by eyeballing. The tolerance for height determination is ± 10 %.

Table 3 Overall distribution of trees by height group (m)

	Types of wood	Up to 5	up to 10	up to 15	up to 20	21 and over	Total pcs.
	Conifers	5126	14919	16827	8543	-	45415
	Deciduous	22545	105155	128934	6307	4023	2 66964
	Shrubs	45402	1989	-	-	-	4 7391
Total		73073	122063	145761	14850	4023	3 59770

The sanitary condition is determined for all trees, taking into account their ornamental value. The qualitative characteristics of the trees are graded as follows: 'healthy', 'weakened', 'withered', 'dead' and 'failed'.

The distribution of trees by sanitary condition was determined for all trees, shrubs, and hedges, taking into account their ornamental value. To determine the condition of the plantation, the coefficient of object condition (plantation viability) QCO 1-5 - qualitative condition of green spaces, taking into account the viability of the object and its potential capacity for further functioning [8]. By "healthy" trees and shrubs in Bostandyk district are 314522 pcs., these are plantings without signs of weakening, with normal development and without damage, i.e. normal crown development and high ornamental value, intensive growth of shoots, pests and diseases are absent (in the winter and early spring period is not determined). In terms of age characteristics, these are mainly young and middle-aged stands. "Weakened" includes 33075 trees and shrubs. This includes stands with insignificant damage or with one-

sided crown branching, medium ornamental value, up to 10% of dried limbs, weak decline, i.e. less than a leaf plate or needles, damaged by 25% of pests and diseases (not identified during the winter period). These are mostly mature stands. Withered" includes 861 trees, i.e. there is a very advanced process of branching (more than 50%) damage by pests and diseases. As a rule, these are mature and overmature stands. "Dried" 3,278 and emergency 8,034. - completely dead trees or shrubs to be felled as a matter of priority. Table 4 below describes trees and shrubs by management measures according to their qualitative condition.

Table 4 Distribution of trees by management action

№ p.p.	Types of greenery	Sanitary pruning	Sanitary felling	Care	Hedge trimming n.m.	Total
1	Conifers	415	342	4465 8	-	5415
2	Deciduous	32168	11741	2230 55	-	66964
3	Shrubs	492	90	4680 9	-	7391
4	Hedge p.m.	-	-	-	51070	
Total		33075	12173	3145 22	-	59770

Management orders are assigned depending on the sanitary condition of the trees. Management measures include: sanitary cutting, sanitary pruning, crown formation, maintenance, forced demolition, replanting and hedge trimming. From all surveyed plantations of a part of trees and bushes 33075 pcs. are appointed sanitary pruning. Sick, withering, dry and damaged branches that cause emergencies are removed. Maintenance work is assigned to 314522 trees and shrubs. This means the care of the soil and the above-ground parts of the plants (nutrition, watering, loosening, etc.). The measure can be prescribed for any trees and shrubs, except for dead, dying and damaged trees and shrubs [9]. Replanting of deciduous valuable trees is also possible (valuable species: lime, chestnut, catalpa, white acacia, oak, etc.); 12173 trees are attributed to sanitary cutting, of which 8034 trees are attributed to sanitary cutting.

- damaged trees. This management measure is assigned for trees of the following status categories: "downtrodden" (partially), "shrunken", "deadwood", "damaged"; 5,370 nm hedge trimming.

2.2. Assessment of the quantitative and qualitative state of green spaces of the Medeu district of Almaty

The survey of the area revealed the following: a total of 472795 pcs. of trees of deciduous, coniferous and bushy species were surveyed. The following is a summary table of the results of the work carried out

The species composition of the plantations was determined as for Bostandyk district, and Table 5 shows a characteristic of the distribution of woody vegetation by species.

Table 5 Distribution of trees by species

№	Types and indicators of green spaces	Quantity, pcs.	Interest
1	Conifers	56794	12
2	Deciduous	392369	83
3	Shrubs	23632	5
Total		472795	100,0

In addition, the hedge is 80636 lm, which is respectively 80.64 km.

In Medeu district, young stands are: 135860 pcs, middle-aged - 307652 pcs, mature -11624 pcs, mature -10213 pcs, overmature - 7446 pcs; of them presented: under 10 years - 67680 pcs; under 20 years - 65411 pcs; 21 - 40 years - 292894 pcs; 41- 60 years - 26404 pcs and over 60 years - 20406 pcs.

Table 6 Informative classification characteristics of grading by age class

Rock composition	Age class	Age groups - age class, (years)				
		Youngsters	Middle-aged	Mature	Ripe	Overmature
Conifers						
Pine, spruce	20	I-II (1-40)	III-V(41-100)	VI(101-120)	VII (121-140)	VIII and v. (141 and v.)
Thuja, Biota	20	I-II (1-40)	III(41-60)	IV (61-80)	V (81-100)	VI and v. (101 and v.)
Juniper	20	I (1-20)	II(21-40)	III(41-60)	IV61-80)	V and Art (81 and Art.)
Deciduous						
Walnut	20	I-II (1-40)	III-IV (41-80)	V(81-100)	VI(101- 120)	VII and Art. (121 and Art.)
Oak,Birch,Lime,Chestnut	10	I-II (1-20)	III-V (21-50)	VI(51-60)	VII(61-70)	VIII and v. (71 and v.)
Maple, Ash, Willow, Elm	10	I-II (1-20)	III-IV (21-40)	V(41-50)	VI(51-60)	VII and v. (61 and v.)
Aspen, Poplar, Acacia, Gledicia,	10	I-II (1-20)	III(21-30)	IV(31-40)	V(41-50)	VI and v. (51 and v.)
Loch	10	I-II (1-10)	II(up to 20)	III(21-30)	IV(31-40)	V and st (41 and st)
Shrubs						
Shrubs are large	5	I-II (1-10)	III(11-15)	IV(16-20)	V(21-25)	VI and v. (26 and v.)
Other shrubs	2	I-II (1-4)	III(5-6)	IV(7-8)	V(9-10)	VI and v. (11 and v.)
Talniki	1	I-II(1-2)	III(3)	IV(4)	V(5)	VI and v. (6 and v.)

The diameter was measured at chest height (1.3 m) using a measuring fork and other methods, including gauging. For trees up to 16 cm in diameter, a two-centimetre thickness step was assumed, and for trees over 16 cm, a four-centimetre thickness step. A tolerance of ±1 thickness increment is allowed. Knowing the diameter of the stand is also necessary when determining age.

The height distribution of plantations in Medeu district was carried out on the basis of the following height groups: 5 m; 10 m; 15 m; 20 m and above 21 m. Tree heights up to 5 m are 110837, up to 10 m - 206891, up to 15 m - 101297, up to 20 m - 50362, from 21 and above - 3408 trees. Table 7 below shows the qualitative condition of trees and shrubs according to the stand condition factor QCO 1 - 5

Table 7 Distribution of trees by sanitary (quality) condition

№ clause.	Types and indicators of green spaces	Qualitative status						Total
		Healthy QCO-1	Weakened QCO-2	Dried out QCO-3	Dry-erecting QCO-4	Emergency QCO-5	Hedge p.m.	
1	Conifers	55989	377	77	308	43	-	56794
2	Deciduous	366863	14472	728	6165	4141	-	392369
3	Shrubs	23422	132	12	66	-	-	23632
4	Live hedge p.m.	-	-	-	-	-	80636	-
Total		446274	14981	817	6539	4184	-	472795

Table 8 below shows the distribution of trees and shrubs by management measure according to their quality status

Table 8 Distribution of trees by management action

No. of the item.	Types and indicators of green spaces	Sanitary pruning	Sanitary felling	Care	Hedge trimming n.m.	Total
1	Conifers	377	428	55989	-	56794
2	Deciduous	14472	11034	366863	-	392369
3	Shrubs	132	78	23422	-	23632
4	Hedge p.m.	-	-	-	80636	-
Total		14981	11540	446274	-	472795

Out of all surveyed stands 472795 part of trees and 14981 shrubs are assigned for pruning. Maintenance work was assigned to 446274 pcs. of trees and shrubs. Sanitary cutting was appointed to 11540 pcs. trees, including 4184 pcs. - broken. Hedge trimming is assigned to 80636 lm.

According to surveys, the total number of tree and shrub plantations is 832795. A total of 113 species of tree and shrub vegetation have been identified. The predominant species is Small-leaved Elm, which accounts for 22 per cent of the total vegetation. The qualitative condition was assessed on the basis of external signs of woody and shrub vegetation. Based on this data 91 per cent or 763796 pcs. are considered healthy plantings and assigned care in the form of irrigation, fertilizing, raising the trunk and pruning. A total of 4,8056, representing 5 per cent, are considered to be weakened. Such plantings are subjected to sanitary pruning of dry and damaged limbs. Due to the number of dead and dying limbs, 4 per cent of the total number of trees and shrubs are subject to sanitary cutting, which amounts to 23713 pcs.

SECTION 3. PERSONAL CONTRIBUTION OF THE AUTHORS, RESULTS OF THE SURVEY AND INVENTORY OF GREEN SPACE

3.1. Results of the analysis on the survey and inventory of green spaces in Bostandyk and Medeu districts of Almaty

The inventory and survey of green spaces were conducted on the territory of Bostandyk and Medeu districts of Almaty city. Green areas are represented by such trees as pine, European spruce, prickly spruce, Tianshan spruce, thuja, domestic apple, green ash, common apricot, white acacia, white birch, squat elm, rough elm, English

oak, cherry, plum and others. stone trees, small-leaved lime, horse chestnut, and shrubs such as common lilac, spirea, hibiscus and others. During the survey of Bostandyk rayon a total of 359770 pieces of trees of deciduous, coniferous and bushy species were identified. All plantings in the area are in a well-maintained condition,

i.e. it is obvious that timely maintenance works such as watering in summer and autumn time, trimming of dry branches and limbs, weeding of rooting circles, etc. are carried out. Mainly young trees are 168858 (46.94 per cent), middle-growth 13503 (37.11 per cent), mature 27715 (7.70 per cent), mature 21282 (5.91 per cent) and overmature 8412 (2.34 per cent). 12173 trees were attributed to sanitary cutting, of them 8034 pcs. - faulty trees.

The survey of Medeu district of Almaty revealed a total of 472795 pcs. of trees of deciduous, coniferous and shrub species. A total of 113 species of tree and shrub vegetation were identified. All plantings in the area are in a well-maintained condition,

i.e. it is obvious that timely maintenance works are carried out, such as watering in summer and autumn, trimming of dry branches and limbs, loosening of soil in the planting circles, etc. Mainly young trees 135860 pcs, middle-growing trees 307652 pcs, mature trees 11624 pcs, mature trees 10213 pcs, overmature trees 7446 pcs. Sanitary cutting of 11540 trees, including 4184 trees. - damaged trees. Hedge trimming is assigned to 80636 lm. In the future it is recommended to carry out maintenance works and sanitary cutting of old-aged (low-value soft-leaved species - over 80 years) and decaying trees. Instead, other (more valuable species - lime, chestnut, acacia, oak, etc.) ornamental trees of deciduous and coniferous species, as well as beautifully flowering, high growth class and highly phytoncidal shrubs should be planted.

When comparing the 2002 inventory data, the following picture is observed: In 2002, the population of Medeu district was 146.2 thousand people. At the same time, the total number of trees was 238.0 thousand, which per every 100 people was -162.8 pcs. In 2020, Medeu district with a population of 204.9 thousand people, with a total number of trees 472.8 thousand pieces, which per every 100 people is - 230.7 pieces. With the average cover of one tree for the conditions of Almaty (3x3 m) - 9m.2 provision with green plantings accordingly will be per 1 person by years: in 2002. - 14,65 m2 and 2020. - 20.79m2. According to SNiP RK 3.01-01-2008 the area of landscaped public areas for the largest city must be at least 10 m2 per person.

3.2 Recommendations for the maintenance and protection of urban green spaces

In order to improve the qualitative and quantitative condition of the city's green spaces, a number of measures need to be implemented:

Develop recommendations on the regulatory framework for technological processes of landscaping works. At the moment there are no approved recommendations.

Develop a General Landscaping Scheme and its phased implementation (as a section of the City General Plan). There is currently no scheme in place.

Carry out a plantation survey using dendrochronology methods on the main thoroughfares within the historic centre. No such work has been carried out to date.

Restore the landscaping infrastructure of the city and equip it with the necessary

modern specialist equipment, machinery and units for landscaping works, including equipment for chemical protection of plantations. At the moment, the existing landscaping infrastructure is mainly aimed at creating the development of floral landscaping. There is a lack of specialised machinery for planting and replanting trees with bark.

Establish a system for watering green spaces and apply appropriate fertilisers.

In the future, it is recommended that:

Carry out maintenance and sanitary cutting of old-age (low-value soft-leaved species - over 80 years old) and dying trees. Replace them with other (more valuable species - lime, chestnut, acacia, oak, etc.) ornamental trees of deciduous and coniferous species, as well as beautifully flowering, high growth class and highly phytoncidal shrubs.

Provide for the creation of greenery in residential areas of the city (allowed minimum)16 m2.

CONCLUSIONS

The following tasks were carried out in this research study:

1 The methodology for conducting an inventory of green spaces of cities and settlements of the Republic of Kazakhstan, developed in accordance with regulatory documents, has been studied.

2 An assessment of the qualitative and quantitative characteristics of green spaces in Almaty was carried out on the example of Bostandyk and Medeu districts.

3 Recommendations on the maintenance and protection of green spaces in Almaty have been developed.

Thus, according to the surveys, the total number of tree and shrub plantations is 832795. A total of 113 species of tree and shrub vegetation have been identified. The predominant species is Small-leaved Elm, which accounts for 22 per cent of the total vegetation. The qualitative condition was assessed based on the appearance of the woody and shrub vegetation. Based on this data 91 per cent or 763796 pcs. are considered healthy plantings and assigned care in the form of irrigation, fertilizing, raising the trunk and pruning. A total of 4,8056, representing 5 per cent, are considered to be weakened. Such plantings are subjected to sanitary pruning of dry and damaged limbs. Due to the number of dead and dying limbs, 4 per cent of the total number of trees and shrubs are subject to sanitary cutting, which amounts to 23713 pcs.

It is also suggested as a recommendation:

1 To develop recommendations on the regulatory framework of technological processes for carrying out landscaping works. At this time, there are no approved recommendations.

2 Develop a General Scheme of Landscaping and its phased implementation (as a section of the General Plan of the city). There is no diagram at this time.

3 Conduct a survey of plantations using dendrochronology methods on the main main streets of the city within the boundaries of the historical center. To date, these works have not been carried out.

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OPTIMIZATION OF ANAEROBIC FERTILIZATION PARAMETERS OF CATTLE MANURE WITH WINE-MAKING WASTE TO OBTAIN MORE BIOGAS YIELD ON TYPICAL BIOGAS PLANTS.

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Abstract. *The aim of the work is to increase biogas output and generation of electricity in biogas plants due to the joint fermentation of cattle manure with winemaking waste. To achieve this goal, the following tasks have been solved: the biogas yield from cattle manure with winemaking waste was determined during periodic loading of the digester; based on the obtained experimental data, a mathematical model was calibrated to estimate the biogas yield during fermentation of cattle manure with the addition of winemaking waste. Because of the studies, it had been found that when manure was fermented with part of the water replaced in the substrate 2% of the winemaking waste, the fermentation dynamics in the substrate are similar to the fermentation of pure cattle manure. Biogas obtained by fermentation of manure with the addition of 2%, 6.5% and 13% of wastewater from wine production instead of water in the first day of fermentation either did not burn at all or burned poorly. The addition of winemaking waste to a substrate based on manure in an amount of 13% allows increasing the maximum biogas yield by a third to 1,372 l/(hr×kg dry organic matter). The significance of the research results lies in the fact that the use of winemaking waste as a substrate will allow a third increase in biogas output and power generation, and a reduction in the payback period of a 4,4 MW biogas plant using the green tariff to 6,5 years.*

Keywords: *biogas, substrate, cattle manure, winemaking waste, dry organic matter, digester, biogas plant, methane fermentation.*

I. INTRODUCTION

As you know, cattle manure is often used to produce biogas, from which electrical and thermal energy is generated. However, due to the presence of a large amount of crude fiber in manure, the yield of biogas when it is fermented using biogas plants is relatively low. Therefore, an urgent task is to increase the yield of biogas from cattle manure through the use of various stimulating additives. If such a stimulating additive is a waste product, then the problem of its disposal is solved, thereby improving the ecological situation in the region.

In order to increase the yield of biogas and generate energy, it is currently widely co-fermentation of cattle manure with corn silage is practiced. However, this raw material can be used as animal feed and human food. Therefore, to increase the yield of biogas from cattle manure, it is advisable to use cheaper raw materials that stimulate the yield of biogas - production waste that must be disposed of at minimal cost, while improving the environment.

The aim of the work is to increase the yield of biogas and the generation of electricity from cattle manure by adding a stimulating additive in the form of winemaking waste.

To achieve this goal, it is necessary to solve the following tasks:

- determine the yield of biogas from cattle manure with the addition of winemaking waste with periodic loading of the digester;
- evaluate the yield of biogas during the fermentation of cattle manure with the addition of winemaking waste;
- using a mathematical model to predict the yield of biogas and the generation of electricity for the quasi-continuous loading of the digester.

II. LITERATURE ANALYSIS

As shown in [1], the yield of biogas from the fermentation of corn silage (650 m^3/kg VS) or food waste (660 m^3/kg VS) is significantly higher than from animal manure (450 m^3/kg VS). Fermentation of winemaking waste with cattle manure in a fixed film laboratory reactor at a temperature of 35°C provides a methane yield of 1048 l/kg VS. At the same time, an increase in the total methane yield was also recorded in comparison with mono-fermentation of cattle manure [2]. The paper [3] presents the results of a study of the process of methane fermentation of red wine production wastes with a high tannin content (2–3 g/l) and high sulfate concentrations (3–8 g/l). It has been established that tannins do not inhibit the formation of acid and the reduction of sulfate in the acidogenic phase. Even at a concentration of 800 mg/l in the acidogenic reactor, 30% of the tannins were degraded. The concentration of tannins 500 mg/l in the methane reactor proportionally limited the methanogenic biological activity by 20%.

The paper [4] presents the results of a study of the possibility of utilizing wastewater from primary winemaking by methane fermentation, which in turn is the rationale for using methanogenesis as the most effective method for treating highly concentrated wastewater. Humidity of wastewater from wineries with sediment is 92%, which is the optimal value for an efficient methane digestion process. The C:N ratio varies from 20:1 to 100. Wastewater from primary wineries is characterized by a slightly alkaline environment, the pH value of which is 7.4 with an acceptable pH value of the medium, at in which the process of methane formation proceeds stably, in the range of 6.5-7.5.

The results of the studies presented in [4] allow us to conclude that the process of biogas formation begins 22 hours after loading the substrate, and as the biogas yield increases, the content of methane in it also increases. The maximum yield of biogas was observed on the 21st day of fermentation and amounted to 5.65 dm^3/day with a methane content of 67%. In [5], the average composition of wastewater from wineries is given. Wastewater from the main production of primary winemaking plants has the following indicators: COD = 380-6400 mg O_2/dm^3, BOD = 300-4300 mg O_2/dm^3, pH = 4.7-7.5, recycling shops: COD = 4000-30000mg O_2/dm^3, BOD = 2800-23000 mg O_2/dm^3, pH = 4.4-6.0, secondary wineries: COD= 80-1000 mg O_2/dm^3, BOD = 40-900 mg O_2/dm^3, pH = 7.2-9.6.

As indicated in [5], the use of modern digesters makes it possible to maintain a high concentration of biomass in the fermentation zone (60–80 g/dm^3), increase the load to 17–18 kg COD O_2/m^3 of the digester, and days.

In [6], the high yield of biogas from winemaking waste was 855.5 l/kg VS (774.5 l/kg DM), in [7] - from 400 to 600 l/kg COD, in [8] and [9] - 9 m^3 CH_4/m^3, while in [10] - 172 ml/h VS, in [11] - 207 ml CH_4/h COD, and in [12] -43 ml CH_4/h VS. The yield of biogas from the drains of banana wines when loaded into the fermenter 62.4 m^3/day, according to [13], was 163 m^3/day.

As indicated in [14], methane fermentation of effluents from juice and wine production plants with sludge grinding for 15 days made it possible to obtain a cumulative biogas yield of about 1600 ml/h VS, without grinding - about 800 ml/h VS.

In works [15-18], a study was carried out of the joint fermentation of winemaking waste with activated sludge under mesophilic conditions, the biogas yield in this case was 0.4 m3/kg COP, while in work [19] with fermentation in thermophilic conditions - 0.64 l /h VS (for comparison, when fermenting only activated sludge, the biogas yield was 0.38 l/h VS), and with sonication, 1.411 l/h VS [20]. The authors recommend for thermophilic digestion per part activated sludge add three parts of wine drains.

The research results presented in [21] show that in the process of winemaking, in addition to wastewater, many by-products are formed, mainly grape seeds, grape stems and wine sediments. Anaerobic digestion is particularly suitable for the treatment of winemaking waste due to its high content of nutrient-rich organic matter and significant energy potential. The paper shows that today only the results of mesophilic tests are widely presented. In this study, potential methane production and kinetic constants were determined using periodic tests under thermophilic conditions and compared with mesophilic values already known in the literature. It is shown that from grape waste produced in Italy (808 thousand tons per year) according to the Italian scenario, about 245 GWh can be produced. thermal and 201 GWh. electrical energy per year.

The study [22] provides an estimate of the production of biogas and methane from grape pomace (Cabernet Franc variety). The physical and chemical characteristics of the raw materials were determined, and the structural polysaccharides were identified and analyzed by the Van Soest method. To assess the production of methane from grape pomace, pulp and seeds, periodic anaerobic digestions were carried out. At the same time, the effect of biomass grinding by its mechanical pre-treatment on the methane potential was evaluated. It has been shown that biomass pre-treatment increases anaerobic biodegradability for grape pomace, pulp and seeds by 13.1%, 4.8% and 22.2%, respectively.

The work [23] presents the results of experiments on laboratory installations to assess the yield of biogas and methane obtained as a result of anaerobic digestion of fresh grape waste. Experimental results show that the methane yield reaches up to 110 m^3/t with a higher productivity than from other types of biomass. The inclusion of grape seeds has a positive effect on the production of biogas and methane. In addition, at using crushed grape waste, a higher percentage of CH_4 can be achieved.

The analysis of the conducted studies shows that further study of the issues of intensifying the output of biogas and generating electricity based on the fermentation of cattle manure with stimulating additives is required. At the same time, in the works considered above, the assessment of the biogas yield was carried out only according to the data of experimental studies, which requires significant time and cost costs, especially with periodic loading of substrates. Although at the present time a large number of modern biogas plants operate in a system with quasi-continuous (gradual) loading.

One of the approaches to eliminate these shortcomings is the use of mathematical models for predicting the yield of biogas during the transition from periodic to quasi-continuous loading of the digester.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

To conduct the study, we used a laboratory biogas plant with a 30 L methane tank, a wet gas tank (Fig. 1) and periodic loading of the substrate, in which the methane tank is completely filled with a fresh portion of the substrate, which is removed from it only after the end of the methane fermentation period. The digester I is heated by a water jacket with an electric heater. The loading of fresh substrate into the lower part of the active zone of the digester is carried out through the digester tube, which ensures the displacement of the spent digestate at the level of the boundary of the substrate and biogas. When filling the digester, it is necessary to keep at least 1/3 of the spent digestate in it for the microflora of the complex of methane-forming bacteria to remain unchanged. The biogas output is recorded on a scale calibrated in centimeters. raising the level gauge cylinder of the wet gas tank. Biogas is burned on a gas stove, while heating water in a calorific value meter [24].

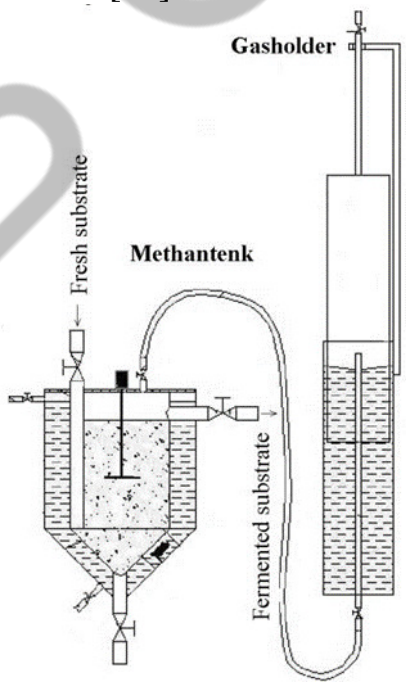

Fig. 1. Laboratory biogas plant. [1]

For experiments with the addition of VTOL, the substrate was prepared by adding crushed grape ridges to tap water in a ratio of 10:1. During the studies, part of the water in the substrate was replaced by wastewater from wineries, as shown in Table. 1.

Table 1[2]. The composition of the substrate in the study of the effect of wastewater from wineries on the yield of biogas during methane fermentation cattle manure

Indicator	№ experience			
	1	2	3	4
Cattle manure, kg	3	3	3	3
Moisture, kg, wherein:	4,5	4,5	4,5	4,5
Water, kg	4,5	4,35	4	3,5
VTOL, kg	0	0,15	0,5	1
%	0	2	6,5	13
The content of SOM in the substrate, kg	0,46	0,40	0,41	0,42
%	5,44	5,34	5,47	5,65
Relative Humidity substrate, %	93,40	93,5	93,4	93,2

The average measured pH of the substrate at a content of 2% VTOL in it was 7.86, at a content of 6.5% VTOL - 7.4, at content of 13% VTOL - 7.38.

The digester was half loaded with substrate (load factor - 0.5). When a new portion of the substrate was added, the fermented substrate changed by half (emptying coefficient - 0.5). That is, with a new load, 7.5 kg of substrate was added to the digester. As a substrate, cattle manure (solid fraction) collected on a pasture with a relative humidity of 84% was used. 3 kg of manure diluted with 4.5 kg of liquid (water or its mixture with SVVV) was loaded into the digester.

The fermentation temperature was 40°C.

IV. RESULTS

Investigation of the biogas yield during the fermentation of cattle manure with the addition of VTOL. On fig. Figure 2 shows the results of studies, from which it can be seen that during the fermentation of cattle manure and the replacement of part of the water in the substrate with 2% VTOL, the dynamics of fermentation in the substrate is similar to the fermentation of pure cattle manure [24]. In this case, the biogas yield gradually increases over time, and then also gradually decreases.

An increase in the content of VTOL in the substrate to 6.5% or more somewhat changes the dynamics of the fermentation of the substrate.

The yield of biogas increases sharply over time, and after reaching the maximum, it also falls sharply.

With an insignificant content of HTVP in the substrate, diauxia is observed, which is clearly expressed, while with an increase in the content of effluents in the substrate, it becomes barely noticeable.

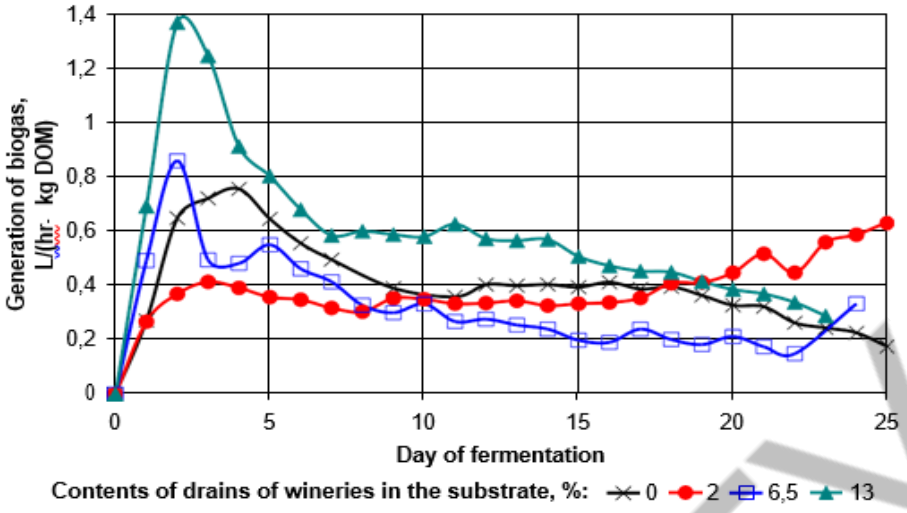

Fig. 2. Dynamics of biogas yield during the fermentation of cattle manure with the addition of wastewater from wineries at a fermentation temperature of 40°C.3

From fig. 2 it is established that the maximum biogas yield at 2% replacement of water with VTOL in the substrate is 0.415 l/(h.kg SOM), 6.5% - 0.862 l/(h.kg SOM), 13% - 1.372 l/ (h.kg SOW).

Biogas obtained from the fermentation of cattle manure with the addition of wastewater from wineries 2%, 6.5% and 13% instead of water, on the first day of fermentation, either did not burn at all, or burned poorly, releasing about 8 MJ / m^3 of biogas according to the express method [25]. On the second day of methane fermentation, biogas combustion stabilized with a calorific value of 14-18 MJ/m^3 according to the express method.

Using the gas analyzer GEM-500, the elemental composition of biogas was determined at various levels of the cylinder-level gauge. In the case of the cylinder-level gauge being at the level of 12.5 cm, the content of methane in biogas was 62%, and the heat of combustion of biogas was 22.1 MJ/m^3. In other cases, biogas for measuring its elemental composition was taken from the gas tank when lowering the cylinder-level gauge to the levels of 19.5 cm, 15 cm, 12 cm, 10 cm, 7 cm, 5 cm, 3 cm. At the same time, the methane content in biogas was 52 %, 55%, 65%, 66%, 68%, 66% and 66% respectively.

Thus, it is advisable to use VTOL for partial replacement of water in the preparation of substrates for biogas production. As a result of the research, it was found that the maximum biogas yield was recorded at a concentration of 13% VTOL. A lower content of VTOL in the substrate does not significantly improve the yield of biogas in comparison with the use of ordinary water for the preparation of the substrate.

Modeling of biogas output at gradual loading of the digester based on the results of experimental studies of biogas yield at periodic loading of the digester. The methane tank of the biogas plant, on which experimental studies of the fermentation of substrates based on cattle manure with the addition of VTOL, was carried out, is designed for periodic loading of the substrate. The mode of quasi-continuous loading of the substrate, when it is loaded in small portions after a certain period of time, as a rule, about 1 hour, is quite difficult to implement on this digester.

At the same time, in practice, in operating biogas plants, the periodic mode of loading the digester is rarely used; more often, the quasi-continuous mode of loading is used, when the substrate is loaded into the digester in small portions after a certain period of time (usually about 1 hour). At the same time, the biogas yield reaches its maximum value with a periodic loading system and remains at this level during the entire time of operation of the biogas plant. Therefore, using the results of experiments with a periodic digester loading system, it is possible to simulate the biogas yield with a quasi-continuous loading system. Based on the data given in [26] and our own research [24], it can be argued that the biogas yield with a quasi-continuous loading system will be close to the maximum biogas yield with a periodic digester loading system.

Let us consider a mathematical model of the functioning of the digester of a biogas plant, consisting of a system of differential equations, in which the growth of the population of methane-producing bacteria is described by the Monod equation, taking into account the dying process, which is given by the Kolpikov equation, and the rate of biogas formation is directly proportional to the concentration of bacteria. The substrate nutrient concentration model takes into account the change in the concentration of substrate nutrients over time, loaded with the substrate into the digester, as well as unloaded from it, processed by bacteria and used to form their cellular biomass, into energy production to maintain their vital activity and biogas production:

$$\begin{cases} \dfrac{dC}{dt} = \left(\dfrac{\mu_m \cdot S}{k_a + S} - \dfrac{\mu_d \cdot k_b}{k_b + S} - p \right) \cdot C \\ \dfrac{dS}{dt} = p \cdot (S_0 - S) - \left(k_\alpha \cdot \mu_m \cdot C + \dfrac{k_\beta \cdot S \cdot \mu_m}{k_a + S} \cdot C + k \cdot \rho_б \cdot \rho_c \cdot \dfrac{dV_г}{dt} \right) \cdot \dfrac{1}{\rho_c} \end{cases}, \quad (1)$$

where C is the concentration of bacteria, kg/m^3; S is the concentration of nutrients in the substrate, kg/m^3; dV/dt - dynamics of biogas output, m^3/(kg. day); p is the dilution factor of the culture with the flow of fresh substrate, day-1; k - coefficient of conversion of substrate nutrients into biogas, kg/kg; $\rho_б$, ρ_c biogas and substrate density, kg/m^3; k_α, k_β dimensionless coefficients of substrate assimilation; k_a is a constant equal to the concentration of nutrients in the substrate, at which the growth rate reaches half the limit, kg/m^3; k_b - empirical coefficient, kg/m^3; μ_d maximum specific rate of death of methane-forming bacteria, day^{-1}; μ_m maximum specific growth rate of methane bacteria, day-1; $K_\gamma$coefficient of conversion rate of substrate nutrients into biogas, m^3/(kg. day); t - time (day).

The initial conditions for solving a system of differential equations are:

- initial concentration of biomass of methane-producing bacteria (C_0) in the digester -1 kg/m^3;

- initial concentration of nutrients substances in the substrate (S_0) was determined from the results of experimental studies: 8.5 kg of the substrate, incl. 3.5 kg of cattle manure and 5 kg of water; hence,

$S_0 = 3{,}5\ (30 \cdot 1000) = 115$ kg/m^3;

- initial output of biogas $V_0 = 0$ m^3/m^3.

Taking into account the fact that 0.27 g of methane is formed from 1 g of acetic acid, the coefficient of conversion of substrate nutrients into biogas is taken as k=0.27.

In the case of periodic loading of the digester, the relative rate of substrate inflow is p=0 day^{-1}, and for the quasi-continuous mode, p>0 day^{-1}.

With quasi-continuous loading, the relative rate of substrate inflow p can be defined as the reciprocal of the hydraulic content time: p=1/tg. At operating biogas plants, tg is close to 20 days, so p = 0.05 day^{-1} [27].

The parameters μ_m, μ_d, k_a, k_b, k_α, k_β, K_γ depend on the temperature regime of the digester and the type of cosubstrate. Biogas density is

1.212 kg/m^3. The density of the substrate is $\rho_c = 1010$ kg/m^3.

In the Simulink package, integrated into the MATLAB program, simulation modeling of the process of fermentation of cattle manure with the addition of wastewater from wineries was carried out. As a result, the dynamics of biogas output was obtained as shown in Fig. 3.

In addition, the results of simulation modeling of the biogas yield dynamics were compared with the results of experimental studies. By selecting the parameters μ_m, μ_d, k_a, k_b, k_α, k_β, K_γ the simulated model presented in the Scope of the Simulink package was closest to the time dependence of the biogas yield obtained experimentally (see Fig. 2).

The yield of biogas was measured in m^3/kg, since during experimental studies the yield of biogas was determined from 1 kg of the substrate.

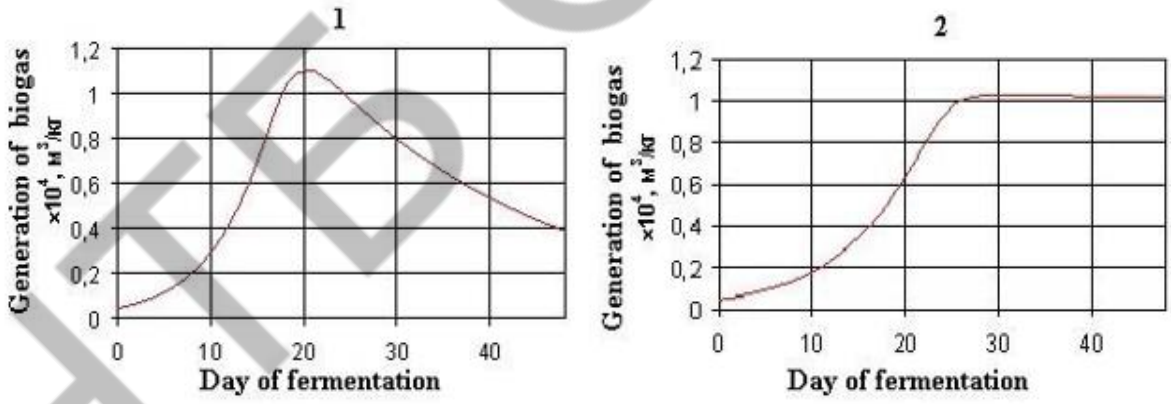

Fig. 3. Dynamics of biogas yield obtained as a result of process simulation fermentation of cattle manure with the addition of wastewater from wineries: 1 - with periodic loading of the substrate; 2 - with a quasi-continuous substrate loading.4

The degree of approximation of the results of simulation modeling of biogas generation to the yield of biogas obtained experimentally was estimated by the coefficient of determination.

The coefficients of the simulation model of the biogas output during the fermentation of cattle manure with the addition of VTOL with their different content in the substrate at a fermentation temperature of 40°C are given in Table. 2.

Table 2. The coefficients of the simulation model of biogas output during the fermentation of cattle manure with the addition of wastewater from wineries with different content in the substrate at a fermentation temperature of 40 °C

VTOL content, %	μm, day $^{-1}$	μd, day $^{-1}$	$K\gamma$, m^3/(kg day)	R^2
2,0	2,4	0,085	0,00000093	0,9041
6,5	2,1	0,09	0,00000195	0,9083
13	2,0	0,095	0,00000313	0,9382

During simulation it was assumed that $k_\alpha=10^{-9}$, $k_\beta=5$, $k_a=14$ kg/m^3, $k_b=0,01$ kg/m^3.

Coefficients μm, μd and $K\gamma$ were determined by selection and comparison of data simulation modeling with experimental data to obtain the lowest possible coefficient of determination R^2.

Coefficient μm, in table. 2 can be described by a logarithmic function, and the coefficients μd and $K\gamma$ by a Newton polynomial of the second order:

$$\mu_m = 0,2414 \cdot \ln(Wd) + 0,5514 \text{ at } R^2=0,9863 \quad (2)$$

$$\mu_d = -1,58 \times 10^{-3} \cdot Wd^2 + 3,15 \times 10^{-2} \; Wh - 4,82 \times 10^{-2} \text{ at } R^2=0,9999, \quad (3)$$

$$K_\gamma = -4,1 \times 10^{-9} \cdot Wd^2 + 2,62 \times 10^{-7} \; Wh + 4,23 \times 10^{-7} \text{ at } R^2=1,0, \quad (4)$$

где Wd – содержание СВВП в субстрате, %.

Since the coefficients of determination of the simulation model of the biogas output during the fermentation of cattle manure with the addition of VTOL approach one, they accurately reflect the experimental data. When checking according to the Fisher criterion, the significance of the coefficient of determination was established.

The simulated biogas yield during the fermentation of cattle manure with VTOL for a quasi-continuous digester loading system is approximated by a power function:

$$Vб \text{ mod} = 0,266 \cdot Wd^{0,64} \text{ at } R^2=0,9992, \quad (5)$$

where Vb mod is the simulated biogas output for a quasi-continuous digester loading system, l/kg COP; Wd is the content of wastewater from wineries in the substrate, %.

The novelty of the work lies in the fact that according to the data of experimental studies of the biogas yield in a periodic loading mode, using the developed mathematical model implemented in the Simulink package, it is possible to predict the biogas yield for a quasi-continuous loading of a digester.

When fermenting manure from a farm for 1,000 head of cattle (of which 500 dairy cows), the daily output of biogas will be 10.6 thousand m^3. At the same time, the payback period of a biogas plant with a capacity of 2.3 MW, consisting of two digesters with a volume of 2500 m^3 each (one of which acts as an after-fermenter, where up to 20% of biogas is produced) at the price of electricity obtained from biogas at a "green" tariff, 0.157 $ /kWh is 10.1 years. The annual production of electricity from biogas combustion in a cogeneration plant is 27.9 million MJ (7.8 million kWh). At the same time, 7.7 thousand Gcal of thermal energy is also produced, which, in addition to maintaining the thermal balance of digesters, can be used for domestic needs.

When disposing of wine-making production wastes by their methane fermentation together with cattle manure from a farm for 1000 heads, the daily biogas

output will increase to 20.5 thousand m^3. The annual production of electricity will increase to 54.7 million MJ (15.2 million kWh), thermal energy - up to 14.79 thousand Gcal. At the same time, the payback period for a biogas plant with a capacity of 4.4 MW when using the "green" tariff will be reduced to 6.5 years (Fig. 4).

V. CONCLUSIONS

1. As a result of the studies, it was found that during the fermentation of VTOL manure, the maximum biogas yield at 2% water replacement with VTOL in the substrate is 0.415 l/(h.kg of SOM), 6.5% - 0.862 l/(h.kg WTS), 13% - 1.372 l/(h.kg WTS).

2. The predicted biogas yield obtained using the developed mathematical model implemented in the Simulink package with a quasi-continuous loading of the digester and the results of experimental studies of the biogas yield with a periodic loading mode with the addition of 13% winemaking waste to cattle manure at peak points completely coincide.

3. When implementing a new methodological approach to predicting the biogas yield, the calculation results show that the use of winemaking waste as a co-substrate will increase the daily biogas yield at a biogas plant in a farm with a population of 1000 cattle to 20.5 thousand m^3, annual electricity production - up to 54.7 million MJ (15.2 million kWh), thermal energy - up to 14.79 thousand Gcal. At the same time, the payback period for a biogas plant with a capacity of 4.4 MW when using the "green" tariff will be reduced to 6.5 years.

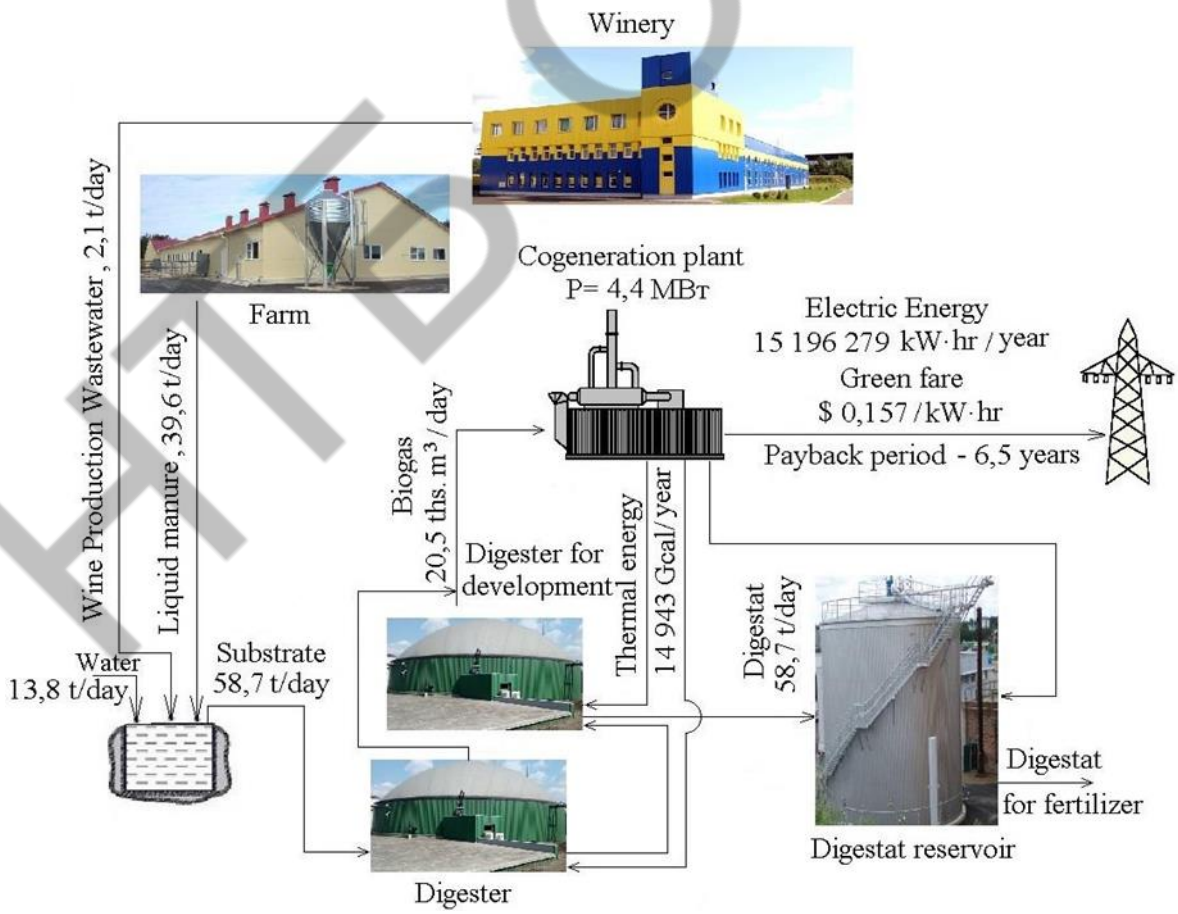

Fig. 4. Scheme for the production of biogas from cattle manure and wastewater from wineries with the generation of heat and electricity.6

Appendix 1

[1]**Fig. 1.** Laboratory biogas plant.

[3]**Fig. 2.** Dynamics of biogas output during fermentation of cattle manure with the addition of wastewater from wineries at a fermentation temperature of 40°C.

[4]**Fig. 3.** Dynamics of biogas output obtained as a result of modeling the functioning of the digester of a biogas plant during fermentation of cattle manure with the addition of wastewater from wineries: 1 – with periodic loading of the substrate; 2 – with quasi- continuous substrate loading.

[6]**Fig. 4.** Diagram of biogas production from cattle manure and wastewater from wineries with the generation of heat and electricity.

[2]**Table 1.** The composition of the substrate in the study of the influence of wastewater from wineries on the biogas yield in methane digestion of cattle manure.

[5]**Table 2.** The coefficients of the simulation model of biogas output during fermentation of cattle manure with the addition of wastewater from wineries with different contents in the substrate at a fermentation temperature of 40°C.

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ILTO RIVER CLIMATE CHANGE SCENARIO

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Abstract. *The research paper refers to the climate change scenario of the Ilto river catchment from 2041 to 2100. The aim of the study is to analyze the extent to which climate change will affect the Ilto river basin from 2041 to 2070 and from 2071 to 2100 based on parameters such as average temperature and average maximum and minimum temperatures, annual precipitation and maximum daily precipitation, average wind speed and relative humidity. The study is based on quantitative data provided by CENN. The analysis showed that from 2041 to 2100, the warming trend will continue in all seasons and annually, the average maximum and minimum temperatures will increase, the annual amount of precipitation will decrease throughout the simulation period, the maximum amount of precipitation during the day and night will also decrease during the period of the study, the annual value of relative air humidity will increase slightly in the period 2041-2070, while a decrease will be observed in the period 2071-2100 indicating that climate change will affect the Ilto catchment.*

Keywords: *Climate Change, Ilto River, Temperature, precipitation, wind speed, humidity.*

I. INTRODUCTION

Climate change and issues related to it have become relevant for Georgian reality after climate-related changes have been observed in Georgia since the 70s of the last century (ფოფია, 2019). Studies on the climate in Georgia show changes in the basic parameters such as air temperature, average annual precipitation, relative humidity, humidity regime, etc., which clearly indicate all trends of climate change in the country (Environment and Security Initiative, 2011).

The impact of climate change on the water catchment basins of the rivers in Georgia has aroused interest. Accordingly, the aim of the study is to analyze the scenario of climate change in the catchment basin of the Ilto[1] River. Therefore, the main research question seeks to investigate the extent to which climate change will affect the Ilto River catchment in 2041-2100. Furthermore, there are sub-research questions which aim to particularly study the extent to which: (1) climate change will affect average temperatures and average maximum and minimum temperatures for the years 2041-2070 and 2071-2100; (2) climate change will affect annual precipitation and maximum daily precipitation during 2041-2070 and 2071-2100; (3) climate change will affect average wind speed and relative humidity for the years 2041-2070 and 2071-2100.

The study is divided into five main parts. After the introduction, the discussion is about the theoretical framework of the research which provides a solid basis for the

[1] Ilto River flows in Kakheti region, Georgia and it is the right tributary of Alazni. The length of the river is 45 kilometers (ფოფია, 2019).

interest in the mentioned issue. The third part describes the methods by which the research questions will be answered. The fourth chapter discusses the climate change scenario of the Ilto River from 2041 to 2100, and the last chapter summarizes the results of the study.

II. LITERATURE ANALYSIS

Climate variability, natural evolution, and human activity combine to drive global change at different scales (Liu, Y., Yu, K., Zhao, Y., & Bao, J, 2022). In particular, climate change may affect water cycle processes, runoff and regional water balance (Liu, Y., Yu, K., Zhao, Y., & Bao, J, 2022).

A paper on the effects of climate change and human activity on runoff in western China showed that temperature has a significant increasing trend, while precipitation, evaporation, runoff, relative humidity, sunshine duration, and wind speed have a decreasing trend (Liu, Y., Yu, K., Zhao, Y., & Bao, J, 2022). Effects of climate change and human activities on runoff showed that until 1985, climate change had a greater impact on runoff reduction than human activity. After 1985, the impact of climate change has decreased and the impact of human activity on runoff has increased (Liu, Y., Yu, K., Zhao, Y., & Bao, J, 2022). Climate change has driven the cycle of precipitation and evaporation, affected the regional water balance and distribution of water, and human activities have altered the hydrological process (Liu, Y., Yu, K., Zhao, Y., & Bao, J, 2022).

Kalugin, in a scientific article about the Lena and Selenga Rivers, emphasizes that the analysis of air temperature anomalies in the period from 1861 to 2005 using a 30-year moving average of the Lena and Selenga basins showed that the average annual air temperature decreased by 0.10C and 0.20C (Kalugin, 2022). The results of the spatial analysis of the attribution of anthropogenic climate change to changes in mean annual air temperature and precipitation showed that the increase in warming from the south to the north, due to the increase in greenhouse gas emissions, was noted in both river basins (Kalugin, 2022). Differential integral curves of Lena and Selenga annual runoff from 1861 to 2005 showed that Lena runoff increased under climate change conditions and anthropogenic greenhouse gas emissions (Kalugin, 2022). Since the 1970s, Selenga runoff has clearly increased under climate change conditions (Kalugin, 2022).

It should be noted that the effects of climate change and anthropogenic activities on flow indicators in a tropical river basin in southern China have been investigated (Xu, F., Zhao, L., Niu, C., & Qiu, Y, 2022). Climate change and anthropogenic activities are the two main driving factors that affect changes in river flow (Xu, F., Zhao, L., Niu, C., & Qiu, Y, 2022). The response of different stream flow indicators to climate change and anthropogenic activities was investigated. Precipitation increased slightly by 24.8 mm, while temperatures increased significantly by 0.230C and sunshine hours decreased by 0.03 hours over the decade (Xu, F., Zhao, L., Niu, C., & Qiu, Y, 2022).

These studies create a concrete scientific framework that emphasizes the fact that climate change affects river basins. Therefore, within the framework of the mentioned literature review, which created the ground for further research, it is interesting to analyze extent to which the climate changes will affect the Ilto River catchment.

III. METHODS OF RESEARCH

In order to give an appropriate answer to the research questions, I have to rely on a project carried out by CENN, which was implemented within the framework of the EU-supported project[2], where quantitative data related to air temperature, precipitation, wind speed and relative air humidity from 2041 to 2100 will be analyzed.. It should be noted that the data obtained as a result of the research carried out by CENN is based on the data recorded in the period 1961-2020 in the catchment basin of the Ilto River. It should be noted that the methodology for the assessment of future changes includes the forecast calculated with the MPI-ESM-MR A1B scenario of the global model, which was reduced to a 20 km grid using the RegCM_v.4.0 regional model for the territory of the South Caucasus region on the basis of which the climate scenarios were built for 33 meteorological stations and the climate forecast was made based on the SRES scenario.

IV. RESULTS OF ILTO RIVER CLIMATE CHANGE SCENARIO

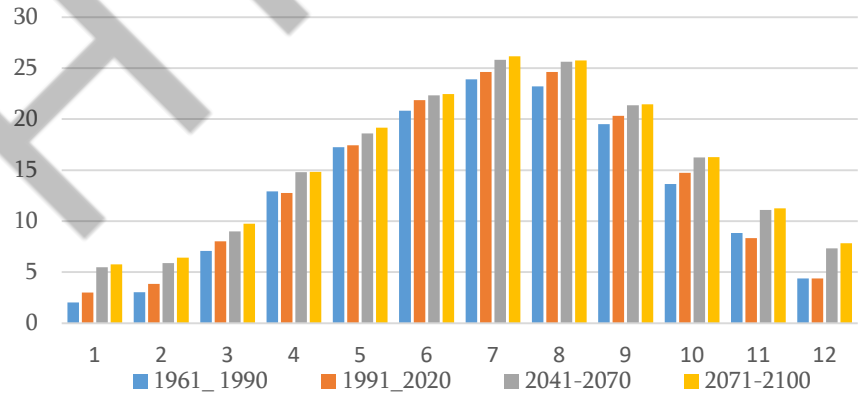
According to the research questions, the changes in temperature, amount of precipitation, wind speed and relative air humidity need to be analyzed. First, temperature variation will be discussed.

According to Figure 1, the warming trend in all seasons and annually continues throughout the simulation period from 2041 to 2100. More specifically, warming up to 2-2.8 degrees is expected from November to March from 2041 to 2070. The smallest increase is expected in the month of June by 0.6 degrees, and the rate of warming for the rest of the months is 1-1.5 degrees. It should be noted that the warming from 2071 to 2100 continues at relatively low rates. The annual warming rate is 0.3 degrees, but depending on the seasons, the warming rate in winter and spring is higher by 0.4-0.5 degrees.

As for the average maximum and minimum temperatures, according to Figure 2, the temperature parameters will increase by 1.2-1.4 degrees annually in the period of 2041-2070. Maximum warming is expected in winter by 2^0C. By the year 2100, both the average maximum and minimum temperatures will increase by 0.9 degrees in winter.

Fig. 1

Average seasonal and annual actual values of temperature for the periods 1961-90, 1991-2020, and values obtained by the scenario for the periods 2041-2070 and 2071-2100. (Akhmeta, ^{0}C)

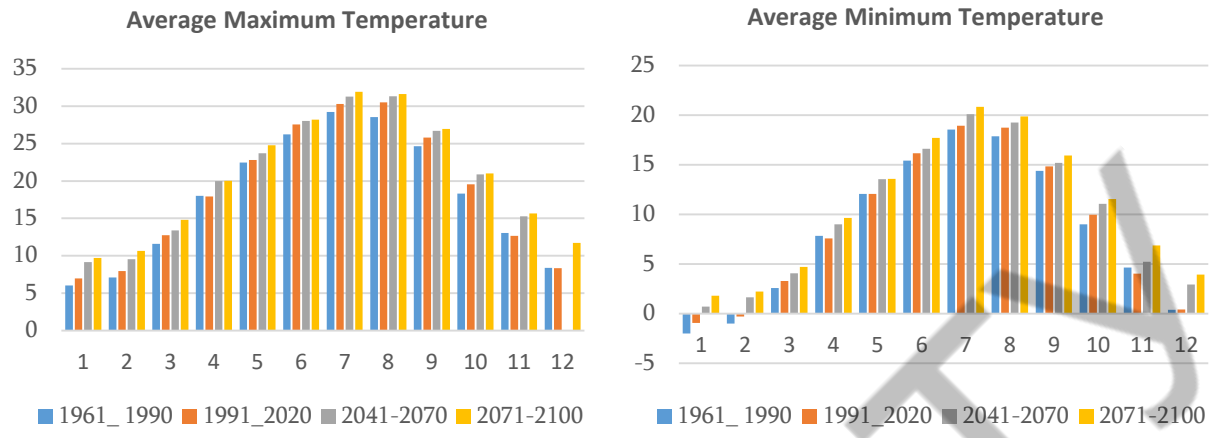


Source: CENN

[2] Georgia Climate Program (GEO-CAP): Promoting Civil Society Engagement in Climate Change Policy Development and Implementation

Fig. 2

Seasonal and annual actual values of the average maximum and minimum temperatures for the periods 1961-90, 1991-2020 and the values obtained by the scenario for the periods 2041-2070 and 2071-2100. (Akhmeta, ^0C)

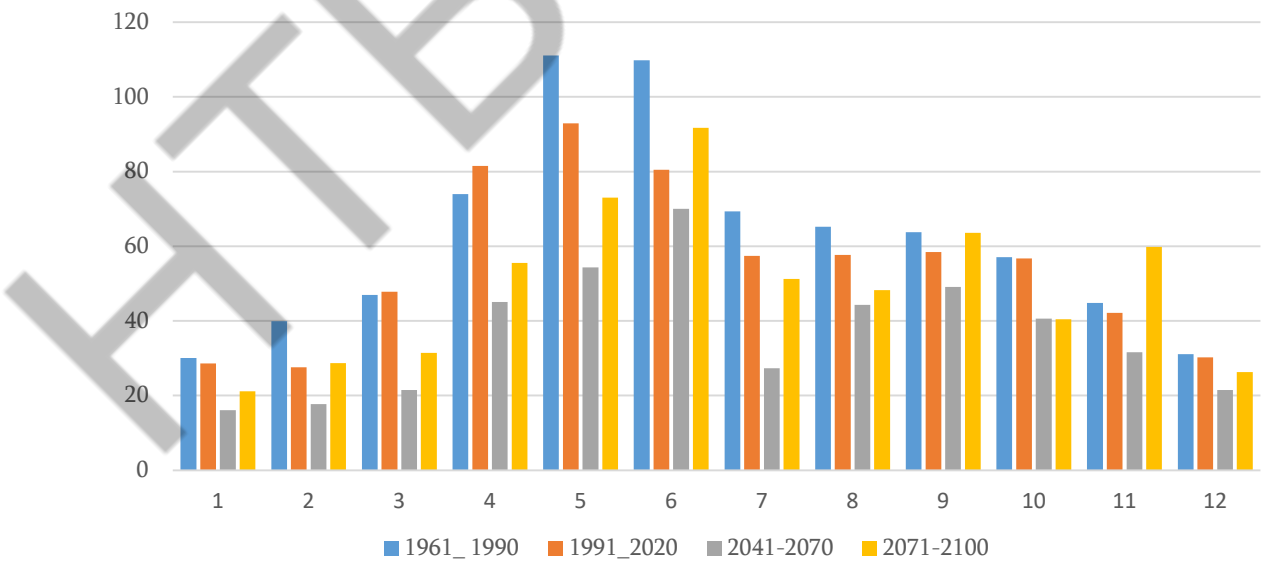


Source: CENN

As shown in Figure 3, the annual amount of precipitation has decreased, especially in the months of May and June. More specifically, the decline from 2041 to 2070 is quite large, as the annual total will decrease by 1/3. The annual amount of precipitation will decrease especially in winter and spring. In the period from 2071 to 2100, the rate will increase compared to the previous period, but the rate will still remain low. It should be noted that the maximum decrease in the amount of precipitation is recorded in the spring season.

Fig. 3

Actual values of seasonal and annual precipitation totals for the periods 1961-90, 1991-2020, and scenario values for 2041-2070 and 2071-2100 (Akhmeta, mm)



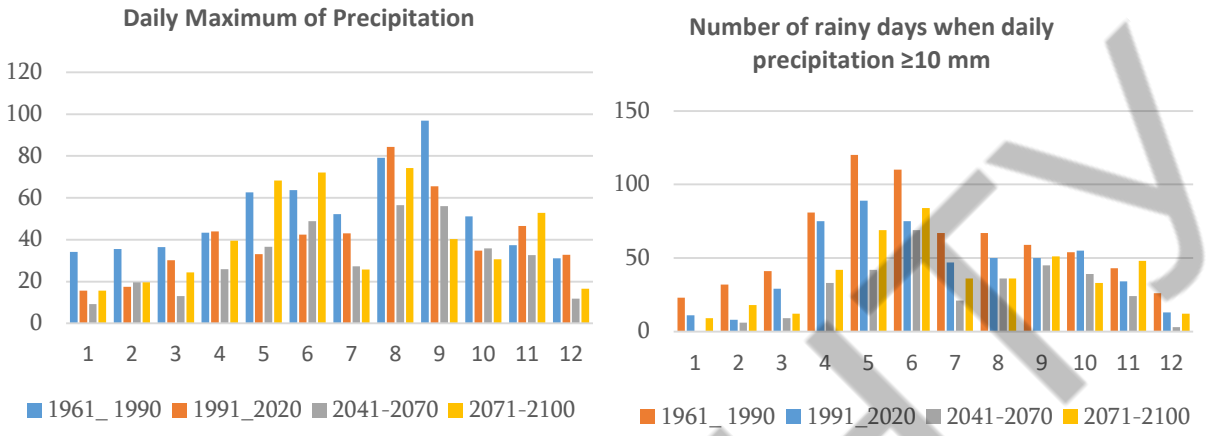
Source: CENN

As for the amount of maximum precipitation during the day and night, it will decrease during the research period and as shown in Figure 4, the maximum will be observed from September to August. For the period from 2041 to 2070, the annual maximum is expected in August. By 2100, the total and daily maximum precipitation

will increase compared to the previous period, but will still remain low compared to the observation period (1961-2020).

Fig. 4

Seasonal and annual actual values of the maximum precipitation during the day and night and the number of days with more than 10 mm of precipitation for the periods 1961-90, 1991-2020, and the values obtained by the scenario for the periods 2041-2070 and 2071-2100. (Akhmeta, mm)

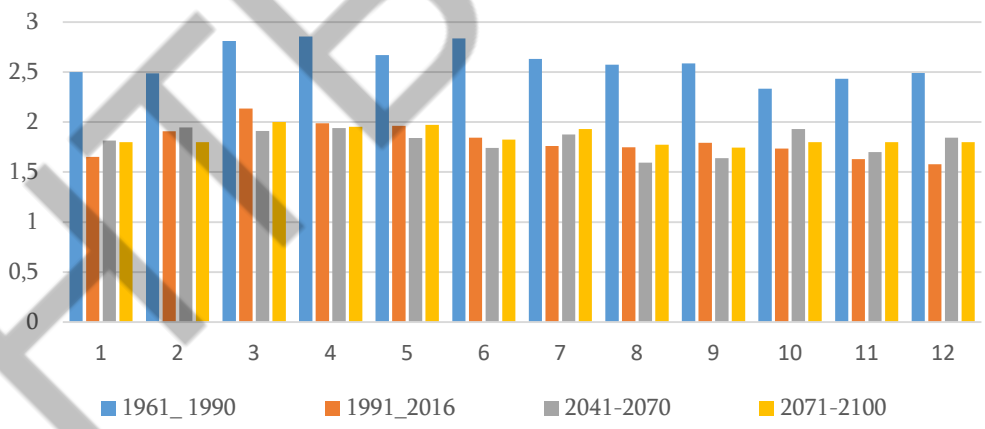


Source: CENN

As shown in Figure 5, the wind speed decreases from 2041 to 2070. Although the rate increases slightly by 2100 in some months, overall variability is small and wind speeds remain low.

Fig. 5

Seasonal and annual actual values of wind for the periods 1961-90, 1991-2020 and values obtained by the scenario for the periods 2041-2070 and 2071-2100 (Akhmeta, m/s).

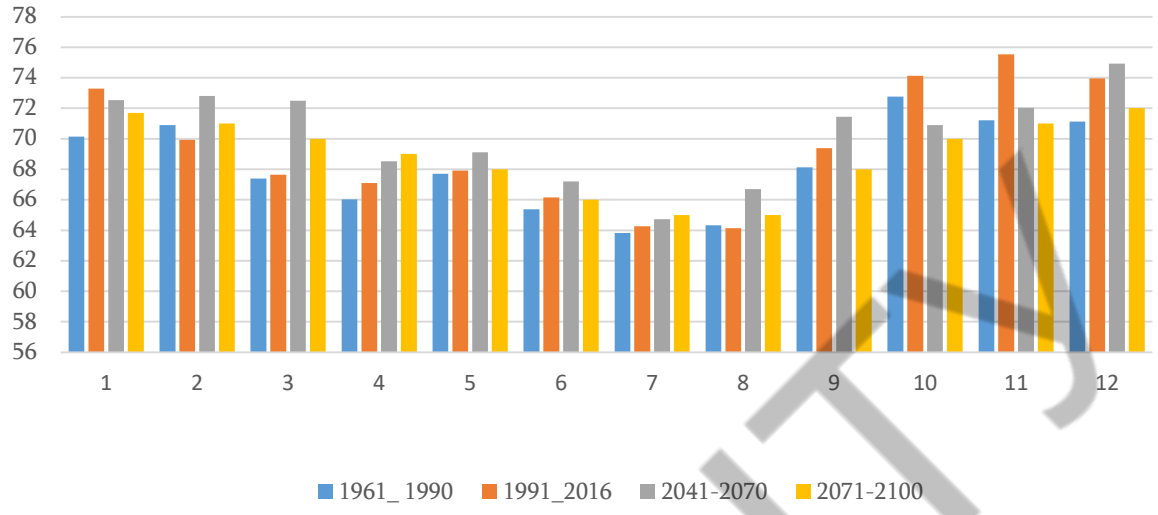


Source: CENN

As for the relative air humidity (Figure 6), the annual value slightly increases within 1% in the period 2041-2070, and a slight increase is followed by a decrease in the period 2071-2100. In the period from 2041 to 2070, an increase of about 2.5% is recorded in spring, in summer and winter the rate increases by 1.5%, and in autumn the relative humidity of the air as a whole decreases. As for the period from 2071 to 2100 compared to the period of previous years, there will be a decrease in each season, more precisely by about 1% in spring and summer, and by about 2% in autumn and winter.

Fig. 6

Average seasonal and annual actual values of relative humidity for the periods 1961-90, 1991-2020 and values obtained by the scenario for the periods 2041-2070 and 2071-2100 (Akhmeta, %)



Source: CENN

V. CONCLUSION

Climate change in Georgia causes changes in air temperature, relative humidity, humidity regime and average annual precipitation. The climate change scenario of the Ilto river basin for the period from 2041 to 2100 was of interest, research aim was to investigate changes regarding average temperature and average maximum and minimum temperatures, annual precipitation and maximum daily precipitation, average wind speed, and relative humidity, and the specific information based on the data recorded in the period 1961-2020 in the catchment basin of the Ilto River was analyzed.

As a result, a scenario was obtained, according to which the warming trend in all seasons and annually continues throughout the simulation period, and the average maximum and minimum temperatures will also increase. Furthermore, the annual amount of precipitation as a whole will decrease in the period of 2041-2100. The maximum amount of precipitation during the day and night will also decrease during the study period. As for the annual value of the relative air humidity, it will increase slightly in the period of 2041-2070, and the slight increase will be followed by a decrease in the period of 2071-2100. Therefore, to conclude, climate change affects the mentioned parameters, which causes the variation of the mentioned indicators in the Ilto catchment basin.

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THE IMPACT OF URBAN PARK RECONSTRUCTION ON THE AGGREGATE STRUCTURE OF SOIL

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Abstract. *The aggregate structure provides the ability to efficiently produce soil ecosystem services. The study examined the impact of park reconstruction on soil aggregate structure. The study was conducted in the recreational area of the Botanical Garden of the Oles Honchar Dnipro National University (Ukraine), where a 2.8-hectare section of the park was reconstructed. Reconstruction work on the park included restoring pedestrian paths, removing shrubs and old damaged trees, trimming tree crowns. Young trees were blown up in place of distant old trees. Old outbuildings that had impaired the aesthetics of the park were also removed. Transport and construction equipment was involved in the reconstruction. There was found that there is an opposite dependence between the size of the fractions and their representation in the structure: the larger the size of the aggregate fraction, the smaller the weight fraction it has. According to the index values, the state of the aggregate structure can be defined as good in a predominant number of cases. The distribution of the aggregate fractions can be described by a gamma law, a normal law, or a mixture of Gaussian laws. The impact of reconstruction and the spatial aspect of variability can explain 15-69% of the variation in the content of aggregate fractions. Under reconstruction, the content of larger fractions decreases, while the content of smaller fractions, on the contrary, increases.*

Key words: *ecosystem services, human ecology, soil quality, environmental management, ecosystems sustainability.*

I. INTRODUCTION

Recreation is one of the anthropogenic factors of influence on nature, in particular on the soil cover and public green spaces, which leads to their significant changes. Nowadays, in countries with high population density, the intensity of recreation has increased dramatically, and accordingly, the anthropogenic impact on natural and artificial biogeocenoses has increased.

One of the main reasons for the disappearance of some plant species and the disintegration of existing communities is the change in the physical properties of the soil caused by the recreational activities. Soil structure is disturbed due to the movement of a significant number of people. Soil is compacted, its bulk density increases. Accordingly, the porosity of the soil, permeability to air, capillary moisture capacity decreases, thermal regime changes. Due to the decrease in water permeability, precipitation does not reach the lower layers inhabited by plant roots. With a lack of moisture, compacted soils dry out even more. Soil conditions are especially changing on the trails, where all vegetation is completely destroyed, roots of tree species are damaged. Under the influence of recreational loads, the degradation of pounds begins.

II. LITERATURE ANALYSIS

The urban park system includes the interaction of human activity, soil, air and biota [1, 2]. Understanding these interactions is essential for managing urban soil and enhancing soil ecosystem functions [3]. Soil surface components of park plantations, such as trees, shrubs and biological crust, as well as human recreational activities, structure the park space into smaller fragments with specific microenvironment, soil and vegetation characteristics [4, 5]. Soil crusts are formed as a result of a close connection between soil particles and cyanobacteria, algae, microfungi, lichens and mosses that live inside or directly on the upper millimeters of the soil. Parks provide a number of ecosystem services such as water and air purification, wind and noise reduction, carbon sequestration, microclimate regulation [6]. In urbanized areas, parks have become "islands" or fragments of habitats for wildlife [7]. They function as green spaces in the city and provide a variety of ecological niches that support and conserve biodiversity. Urban parks perform important social functions such as space for leisure, providing prerequisites for public health, social interaction and entertainment [8–10]. Supporting biodiversity and ecosystem services can be achieved by maximizing the potential of urban green spaces [11]. The activators of ecosystem services of the urban park are the factors that contribute to changes in environmental conditions in the urban soil, resulting in the formation of additional habitats for plants and animals [4]. Implementation of multifunctional "nature-based solutions" contributes to increasing biodiversity through habitat creation [12, 13]. In parks, as in natural areas, vegetation protects the soil from direct radiation and thus restrains the increase in soil temperature and evaporation [14, 15], so that the moisture content in the soil is maintained at a higher level than in the soil without vegetation cover [16, 17]. Parks have a cooling effect [18]. Park plantings create conditions that are favorable for soil fauna [19]. Soil animals increase soil infiltration through digging and bioturbation activities. Soil fauna and forest litter increase organic matter and nutrients in the soil, increase structural stability and soil infiltration. Canopy of trees and shrubs prevents direct impact of raindrops on the soil [20]. This keeps the soil from forming a soil crust, which increases the infiltration capacity and moisture content in the soil. Bare soil is exposed to direct radiation and wind, which leads to an increase in water evaporation and an increase in daily temperature fluctuations [21]. In addition, the soil is directly exposed to raindrops and is therefore subject to greater compaction [22]. All these soil features due to the absence of vegetation cover lead to drier conditions and lower content of organic matter and nutrients in such soil. Grass microhabitat increases soil organic matter content, soil stability and infiltration [23]. Soil and vegetation in parks are heavily influenced by anthropogenic factors [4]. The pressure exerted by visitors leads to soil compaction, which reduces its porosity, moisture and organic matter content, reduces the density, height and species diversity of vegetation cover [24]. Food residues and ashes left by visitors can affect the physical and chemical properties of the soil and the characteristics of herbaceous vegetation [5, 25]. Soil structure is a key factor in soil fertility and agricultural productivity and is therefore of great environmental importance [26]. Soil structure affects the formation of crust [27], ability of plant roots to penetrate the soil [28], movement of groundwater and air [29], CO_2 emissions, erosion, nutrient content and biological activity of the soil [30]. Soil structure depends

on the interaction of soil type, aggregation agents, soil management measures and environmental conditions. The stability of the units has the particular environmental importance such as the dry aggregates by size distribution [31]. The size distribution of dry aggregates is considered as an indicator of soil structure and is one of the main physical characteristics of the soil on which soil fertility and resistance to erosion and degradation depend. The distribution of dry aggregates by size is an informative indicator for assessing the susceptibility of soil to wind erosion, which strongly depends on the size of soil aggregates, especially in arid and semi-arid conditions. The size distribution of dry aggregates is important for improving the predictive ability of pedotransfer functions [32]. Soil structural condition is a valuable soil property for evaluating the effectiveness of tillage. The influence of soil properties on soil structure depends on management and soil typey [33].

One of the most common indices of soil structure is the mean weighted diameter of the aggregate in dry weight (mean weight diameter – dMWD). High dMWD values usually indicate high water permeability and air capacity, but less erodibility of the soil. In Eastern European countries, the structural coefficient (Ks) is mainly used to describe the structural state of soils. This coefficient takes into account the share of agronomically valuable fractions 10–0.25 mm (meso-aggregates) in relation to the share of fractions >10 mm (macro-aggregates) and <0.25 mm (micro-aggregates). The content of agronomically valuable fractions is one of the main indicators of soil quality because they provide optimal porosity and water-air capacity of the soil for plants and soil biota [34]. Soil aggregation can also be expressed by the dry geometric mean diameter (dGMD). This indicator is strongly related to the dust fraction of the soil, which is the most sensitive to deflation, and can be used to predict the risks of wind erosion [35].

Urban parks are usually organized on the site of natural ecosystems such as forests, meadows or steppes. The soil cover of such natural ecosystems had good soil structure and high levels of organic carbon. Anthropogenic soil conversion usually leads to deterioration of soil structure and increased risks of intensive erosion [36, 37]. Soil structure usually deteriorates along with a decrease in soil organic carbon content. Deterioration of soil structure can lead to the initiation of degradation processes such as compaction, accelerated erosion, imbalance of water and salt regime and depletion of soil fertility. As a result of these processes, soil structure deterioration has local, regional and global impacts on the economy, environmental quality and resource sustainability. Increasing the intensity of mechanical impact on the soil can lead to a decrease in meso-aggregates rich in carbon and an increase in micro-aggregates depleted in carbon, which leads to an overall loss of organic carbon [38]. The high performance of the park's ecosystem services depends on the level of management [39]. Urban park management is seen as a tool to achieve the goals of social interaction [40]. The value of ecosystem services of urban parks becomes an important target function of urban green space management [41]. Harmonizing recreational function and maximizing environmental benefits is an important task in park management [42, 43]. Reconstruction is an important tool for park management [44]. The transformation of the vegetation structure is considered the most important goal of parks reconstruction [45]. Soil quality is also one of the main goals in the management of urban parks [46].

Temporal dynamics of soil properties in urban parks is caused by both natural processes [4], and human-driven processes, such as green space management and park renovation. Intensive reconstruction of the park can improve the chemical properties of soils [47]. Information on the spatial distribution of key soil properties (acidity, organic carbon and nutrient content) can be used to predict possible changes in soil cover as a result of green space reconstruction, which is necessary to support urban planning and decision-making on soil management in sustainable cities [48]. Ensuring good soil quality is essential to stimulate plant growth in urban parks and create an environmentally sustainable urban landscape. Thus, soil quality is one of the target functions in the reconstruction of urban parks as an element of the ecosystem services management system. Aggregate structure is an important feature that indicates the condition of the soil and its ability to effectively perform ecosystem services. But the question of the impact of park reconstruction on the aggregate composition of soils has not been studied in modern scientific literature.

Therefore, the aim of our study was to establish the impact of park reconstruction on the aggregate structure of the soil.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The object of research is the aggregate structure of the soil of the test sites of the Botanical Garden of the Oles Honchar Dnipro National University. The subject of the study is the assessment of changes in the aggregate structure of the soil of public green spaces under reconstruction influence. The study was conducted in the recreational area of the Botanical Garden of the Oles Honchar Dnipro National University (Ukraine) (Fig. 1). The artificial forest plantation was created after World War II on the site of a thermophilic natural oak forest [49, 50].

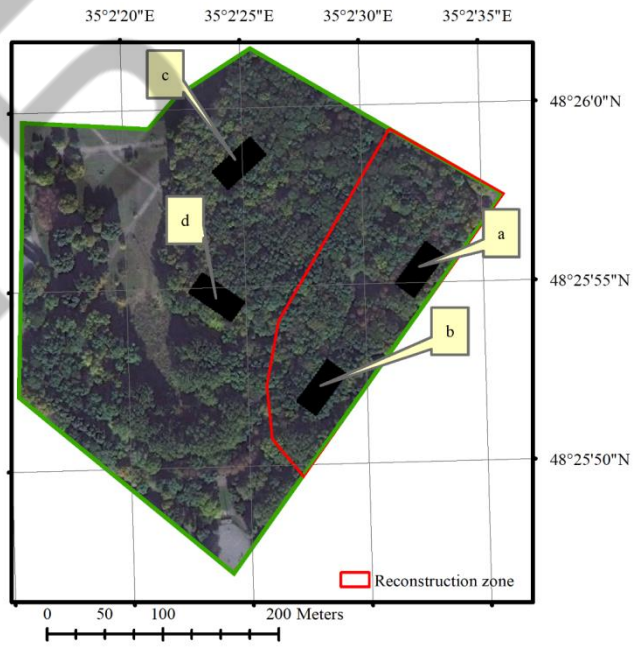

Figure 1. Location of experimental sites within the park.
The red line indicates the park reconstruction zone. Park area without reconstruction (polygons a, b) and park area after reconstruction (polygons c, d).

A total of 65 plant species were recorded in the study area, including 11 species of phanerophytes, two species of non-phanerophytes, 29 species of hemicryptophytes,

16 species of therophytes and 7 species of geophytes [51]. *Acer platanoides, Fraxinus excelsior, Gleditsia triacanthos, Robinia pseudoacacia* were among the rustic plants. *Alliaria petiolata, Chelidonium majus, Geum urbanum, Viola mirabilis, Galium aparine* were among the herbaceous plants. [52].

In 2019, the park area of 2.8 hectares was reconstructed [51]. The park reconstruction works included such processes as restoration of footpaths, removal of shrubs and old damaged trees, as well as pruning of tree crowns. Young trees were planted in place of the removed old trees. Also, old outbuildings that worsened the aesthetic perception of the park were dismantled. Transport and construction equipment was involved in the reconstruction. The works were carried out throughout the warm period of the year.

Soil sampling to measure soil properties was conducted in May 2021 at four sampling sites, 2 of which were located in the reconstruction area and 2 in a similar area of the park where no reconstruction was carried out. Each sampling plot consisted of 105 sampling points. Sampling points were located along 7 transects with 15 sampling points in each transect. The distance between points in a transect as well as the distance between transects was 3 m.

The size distribution of dry aggregates was determined by the standard dry sieving method [53]. The soil sample collected with a 500 cm3 cylindrical sampler was air dried and then sieved through a set of sieves with square mesh sizes decreasing sequentially from 10, 7, 5, 3, 2, 1, 0.5 and 0.25 mm, so that nine aggregate fractions (>10, 10-7, 7-5, 5-3, 3-2, 2-1, 1-0.5, 0.5-0.25 and <0.25 mm) were obtained. The size distribution of aggregates, expressed as a structural coefficient (Ks), was calculated according to the formula [54]:

$$Ks = a / b,$$

where a is the sum of aggregates with size from 0.25 to 10 mm, b is the sum of aggregates with size less than 0.25 and more than 10 mm.

Qualitatively, the state of the soil aggregate structure was assessed by the quantitative value of the structural coefficient [55]: excellent condition (Ks > 4); good condition (Ks = 1.5-4); satisfactory condition (Ks = 0.67-1.5); unsatisfactory condition (Ks = 0.25-0.67); poor condition (Ks < 0.25).

IV. RESULTS

There is an opposite relationship between the size of the fractions and their representation in the structure: the larger the size of the aggregate fraction, the smaller the weight fraction it has (Table 1). This trend is confirmed by the rank correlation of fraction size and percentage (Spearman's coefficient -0.72, p = 0.029). The coefficient of variation, on the contrary, increases with increasing fraction size (Spearman's coefficient 0.82, p = 0.007). According to the index values, the state of the aggregate structure can be defined as good in the vast majority of cases. In a small number of cases, the condition can be assessed as satisfactory or excellent.

Table 1. Descriptive statistics of aggregate fraction content and soil structure indices (%, N = 420)

Indicator	Mean± standard error	Percentile		CV, %	Skewness± standard error	Kurtosis± standard error
		2.5%	97.5%			
Aggregate fractions, mm						
>10	0.14±0.01	0.02	0.44	77.02	1.41±0.12	1.87±0.24
7–10	0.45±0.01	0.07	1.10	63.58	0.78±0.12	0.43±0.24
5–7	0.46±0.01	0.14	0.81	39.57	0.18±0.12	–0.61±0.24
3–5	12.55±0.16	5.25	17.52	26.31	–0.62±0.12	–0.38±0.24
2–3	16.03±0.13	10.69	20.82	16.78	–0.16±0.12	–0.38±0.24
1–2	15.77±0.15	9.75	20.90	19.15	–0.24±0.12	–0.48±0.24
0.5–1.0	12.24±0.07	9.88	15.32	11.03	0.41±0.12	–0.01±0.24
0.25–0.5	12.12±0.06	9.80	14.42	9.57	0.04±0.12	–0.09±0.24
<0.25	30.26±0.30	19.24	42.43	20.04	0.25±0.12	–0.41±0.24
Soil structure indices						
dMWD, mm	1.40±0.01	1.04	1.71	-0.27±0.12	-0.70±0.24	1.40±0.01
dGMD, mm	0.70±0.01	0.48	0.95	0.17±0.12	-0.55±0.24	0.70±0.01
Ks	2.43±0.03	1.35	4.15	0.75±0.12	0.58±0.24	2.43±0.03

Soil structure indices are strongly positively correlated with each other (Fig. 2). The correlation coefficient between dMWD and dGMD is r = 0.92, p < 0.001, the correlation coefficient between Ks and dMWD is r = 0.76, p < 0.001, and with dGMD is r = 0.95.

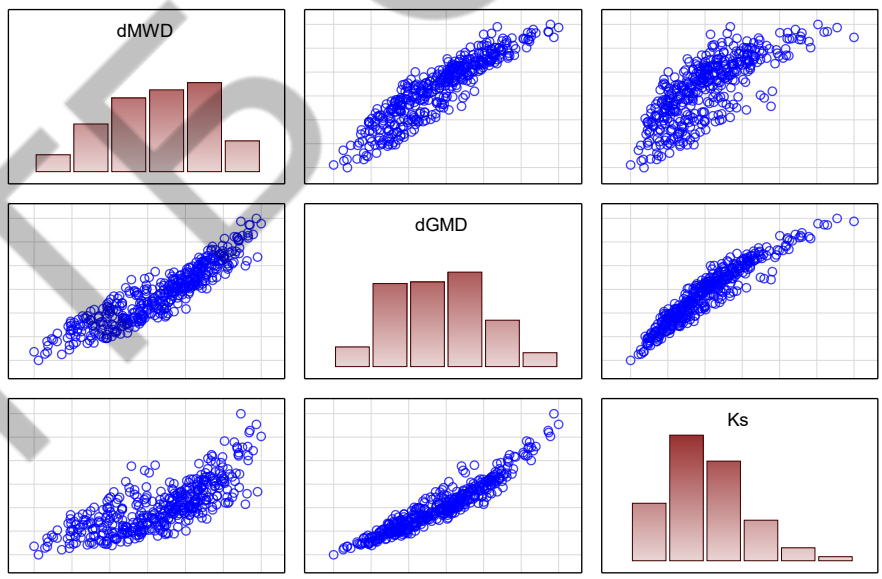

Figure 2. Histograms and scatter plots of average weighted particle size (dMWD), average geometric particle size (dGMD) and structural coefficient (Ks)

The average weighted aggregate size reflects to the greatest extent the changes in the content of aggregates with a size of 2-5 mm (positive correlation) and less than 0.5 mm (negative correlation). The average geometric size of the aggregate reflects the opposite dynamics of the content of aggregates larger than 0.5 (positive correlation)

and less than 0.5 mm (negative correlation). The structural coefficient does not depend on the variation of the content of aggregates larger than 5 mm, but positively correlates with the content of aggregates from 0.5 to 5 mm and negatively correlates with the content of aggregates smaller than 0.5 mm.

The distribution of aggregate fractions can be described by a gamma law, a normal law, or a mixture of Gaussian (normal) laws (Fig. 3). The distribution of large size fractions, whose size exceeds 5 mm, can be best described by the gamma law. The distribution of small size fractions, the size of which is less than 3 mm, can be best described by the normal law. The 3-5 mm fraction is a mixture of normal distributions. The distributions of the mean weighted diameter of aggregates in dry weight and the mean geometric diameter of aggregates in dry weight can be described by a mixture of two normal distributions. The distribution of the structural coefficient values can be described by a normal law.

The influence of reconstruction and the spatial aspect of variability can explain 15-69 % of the variation in the content of aggregate fractions (Table 2). Under the conditions of reconstruction, the content of larger fractions decreases, and the content of small fractions, on the contrary, increases (Fig. 4). As a result of reconstruction, the average size of aggregate fractions and the structural coefficient decrease.

With the help of aggregate fractions, it is possible to effectively discriminate the landfills among themselves (Table 2). The canonical axis 1 differentiates the polygon a from all others (Fig. 5). This polygon is characterized by an increase in aggregate fractions smaller than 1 mm and, accordingly, a decrease in aggregate fractions of larger size. Accordingly, the reverse trend is characteristic for all other polygons. The canonical axis 2 differentiates polygon b from all others. Polygon b is characterized by an increase in fractions smaller than 0.5 mm and larger than 5 mm. Landfills a and b are in the zone of influence of the park reconstruction, so these trends should be considered as a consequence of the reconstruction.

The discriminant model is able to distinguish the landfills by their aggregate composition quite well. Polygons a and b have relatively similar aggregate structure, which explains the observed mutual classification errors. Also, points within polygon b can often be erroneously diagnosed as d. This may indicate that under the conditions of reconstruction, not the entire territory of the landfill was subjected to the same type of anthropogenic impact and some areas remained relatively not strongly transformed. It should also be noted that the points within the d landfill can be relatively often diagnosed as b. This indicates that sometimes under the conditions of normal functioning of the park some areas may be subject to relatively greater anthropogenic pressure.

Our results indicate that the average aggregate size and structural coefficient are highly correlated and actually duplicate each other. Thus, it is enough to arbitrarily choose one of these indices to characterize the aggregate state of the soil. The meaning of using a set of indices is the ability to interpret the results obtained in an ecological way. Thus, a decrease in the average size of aggregates as a result of reconstruction can be considered as evidence of a decrease in the anti-deflationary resistance of the soil, which occurs against the background of deterioration of the aggregate structure in terms of the structural coefficient.

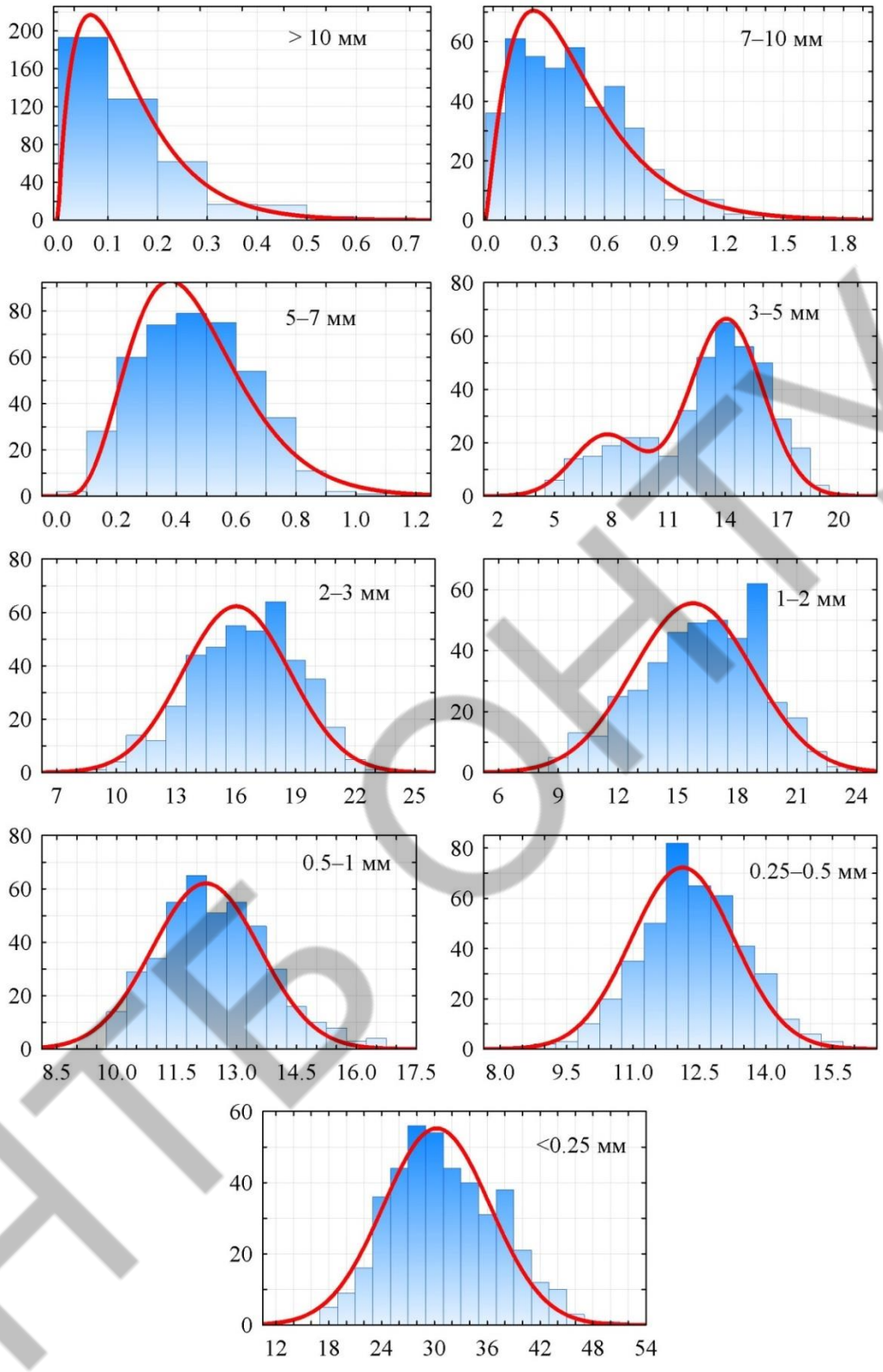

Fig. 3. Distributions of the content of aggregate fractions.
The red line indicates the theoretical distribution: > 10 mm - gamma distribution (KS d = 0.05, p = n.s.), 7-10 mm - gamma distribution (KS d = 0.06, p = 0.2), 5-7 mm - gamma distribution (KS d = 0.06, p = 0.15), 3-5 mm - a mixture of two Gaussian distributions (KS d = 0.03, p = 0.92), 2-3 mm - normal distribution (KS d = 0. 05, p = 0.27), 1-2 mm - normal distribution (KS d = 0.05, p = 0.20), 0.5-1 mm - normal distribution (KS d = 0.04, p = 0.35), 0.25-0.5 mm - normal distribution (KS d = 0.03, p = 0.91), <0.25 mm - normal distribution (KS d = 0.05, p = 0.31)

The reduction of anti-deflationary capacity is undoubtedly a negative trend. It should be noted that the reconstruction involves the thinning of the tree and shrub horizons, which contributes to an increase in the risk of wind erosion. In addition to soil loss, wind erosion in urban environments can negatively affect the living conditions of the population. Along with the negative impact of dust as such, the spread of dust leads to the movement of toxic substances and allergens that are concentrated in the surface layer of the soil. Therefore, the combination of blowing of the area with an increase in the content of the dusty fraction is a very dangerous phenomenon induced by the reconstruction of the park.

Table 2. Results of discriminant analysis of polygons based on information about aggregate structure

Indicator	Canonical axis 1	Canonical axis 2	Canonical axis 3
Aggregate fractions, mm			
>10	0.23	0.11	–0.03
7–10	0.37	0.24	0.10
5–7	0.56	0.26	0.66
3–5	0.80	–0.17	–0.39
2–3	0.17	–0.76	0.00
1–2	–0.29	–0.63	0.39
0.5–1.0	–0.32	–0.24	–0.02
0.25–0.5	–0.27	0.41	–0.11
<0.25	–0.16	0.62	–0.02
Statistics of canonical axes			
Eigenvalue	3.28	1.70	0.53
Canonical R	0.88	0.79	0.59
Wilk's statistics	0.06	0.24	0.65

The soil structural coefficient decreasing indicates a deterioration in the living conditions of soil biota. The deterioration is due to a decrease in the share of meso-aggregates and an increase in the share of micro-aggregates in the structure. This trend may result in colmatation, i.e. the space between meso- and macroaggregates may be densely filled with microaggregates, resulting in deterioration of water and air regime of soils. Also, an increase in the dust fraction increases the risk of crust formation. Soil crust slows down gas exchange and also inhibits the penetration of water that falls on the soil surface with precipitation, while the vertical water runoff, which replenishes soil moisture reserves, changes to lateral, which can accelerate water erosion of the soil.

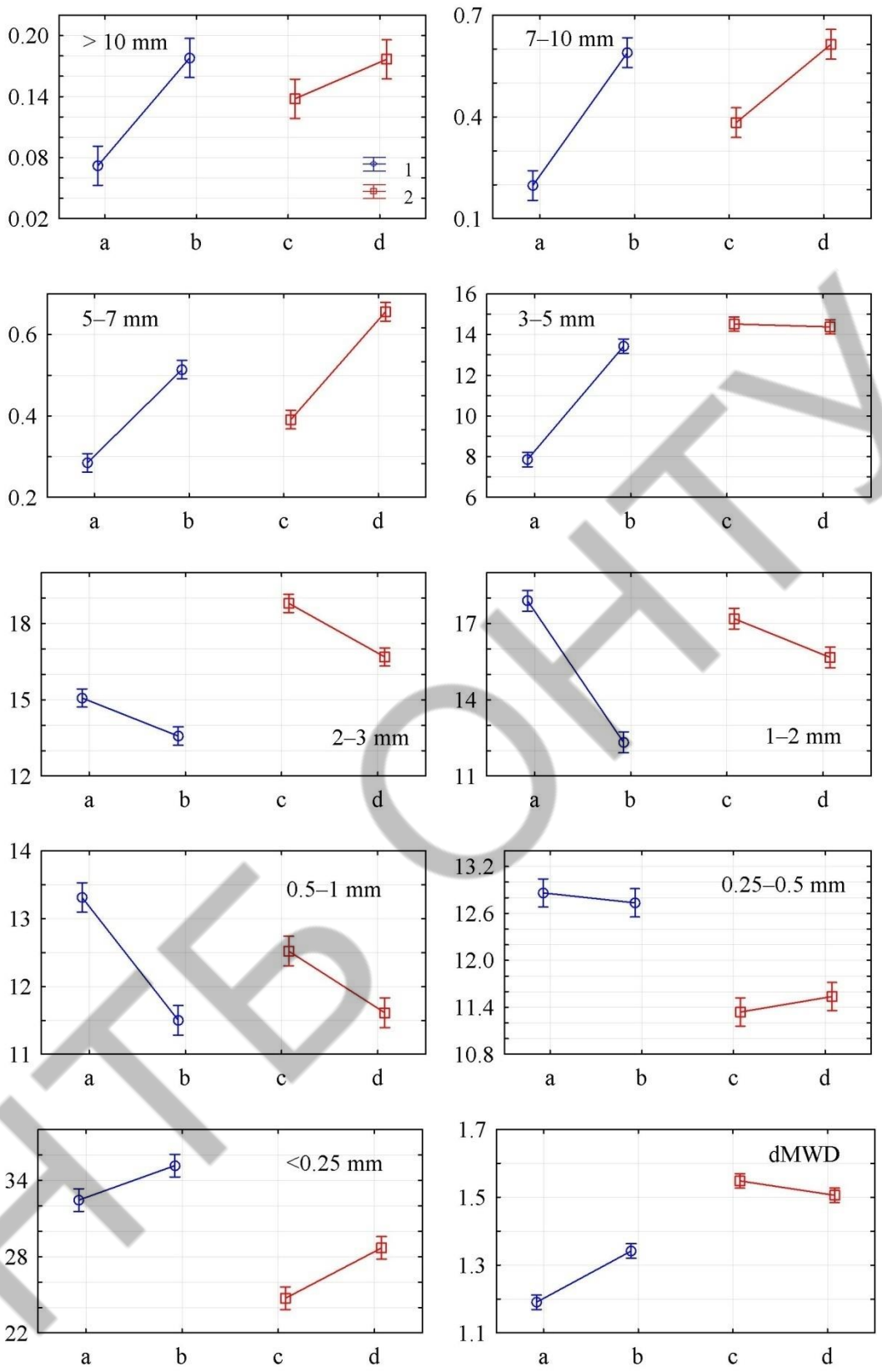

Figure 4. Dependence of the content of aggregate fractions (%) and the average weighted aggregate size (mm) on the impact of park reconstruction and spatial variability. Blue color indicates landfills after reconstruction (a, b); red color indicates landfills without reconstruction (c, d)

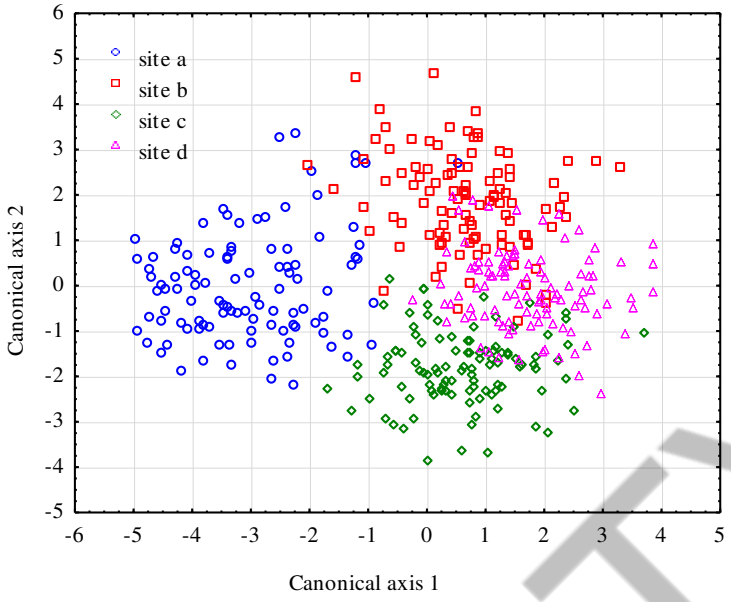

Fig. 5. Position of sampling points in the space of canonical axes

Reconstruction has a heterogeneous effect on the aggregate state of soils. Within the polygon a there is an increase in fractions smaller than 1 mm, and within the polygon b there is an increase in fractions smaller than 0.5 mm and larger than 5 mm. It should be noted that the increase in macroaggregates can have a negative impact due to deterioration of water regime and hyperaeration, but large aggregates have good anti-deflation properties.

Diagnostic levels for soil differentiation after the park reconstruction are fractions of 2-3 and 3-5 mm. Under the influence of reconstruction, their content decreases, obviously resulting in a common increase in the content of the dusty fraction for both landfills. Thus, the main trend in the transformation of the aggregate state of the soil as a result of the reconstruction of the park is the destruction of agronomically valuable meso-aggregates, mainly in the size range of 2-5 mm, and their transformation into a dusty fraction.

V. CONCLUSIONS

Urban parks perform important ecosystem services, the optimization of which requires the development of adequate management procedures, including park reconstruction. As a result of the reconstruction of the park, the ecological regimes of the artificial ecosystem are significantly changed, and when performing technological procedures, there is a significant impact on the environment, especially on the soil cover. The aggregate structure of the soil undergoes changes due to the reconstruction of the park. The main trend of changes is a decrease in the content of aggregate fractions of 3-5 mm in size (mesoaggregates) and an increase in the content of aggregate fractions <0.25 mm in size (microaggregates). Such changes are evidence of negative transformations and a consequence of the decline in the quality of urban soil. To prevent negative phenomena, it is advisable to add to the procedures for the reconstruction of the city park the procedure of creating lawns from plants with fibrous root system to prevent erosion and restore the aggregate state of the soil.

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ENVIRONMENTAL SAFETY OF THE OIL AND GAS COMPLEX

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Abstract. *Ukraine's hydrocarbon transportation system is one of the largest in the world. It is an important element of the international system of oil and petroleum products transportation, as it provides supplies not only to domestic consumers, but also to European countries; contributes to the economic development of Ukraine and the expansion of foreign economic relations.*

One of the most serious problems of operation of main oil and gas pipelines is their accident rate, which is accompanied by disruption of supply of raw materials to consumers, loss of transported products, failure and neutralization of expensive equipment, causing large material damage, fires and explosions, catastrophic impact on the environment.

The environmental safety of pipelines is largely determined by corrosion, because the conditions for its occurrence always exist, and the number of pipeline accidents due to corrosion is growing every year and is about 60%.

The situation is complicated by the fact that the main part of the oil and gas transportation system of Ukraine is outdated. In Poltava region, all main pipelines have been in operation for more than 25 years. Therefore, in the near future, a significant part of the oil and gas transportation system of Ukraine will exhaust its operational life.

Therefore, the problem of ensuring efficiency, operational reliability, environmental safety and increasing the durability of the oil and gas transportation system of Ukraine, including Poltava region, remains relevant and timely, which requires the search for new technical solutions.

Keywords: *transport of hydrocarbon raw materials, environmental hazard, corrosiveness of soil, electrochemical corrosion, local corrosion element.*

I. INTRODUCTION

The oil transportation system of Ukraine is one of the largest in the world. The network of oil pipelines in Poltava region is also quite extensive, because the oil and gas complex of the region is one of the most powerful in the country and combines not only oil production and refining, but also its transportation.

One of the main factors of environmentally safe oil transportation is the technical condition of oil pipelines. As a result of long-term operation of a significant part of oil pipelines, the risk of emergency defects increases, which leads to depressurization of oil pipelines and negatively affects the environment.

The main part of the oil transportation system of Ukraine is outdated: the duration of operation of 70% of oil pipelines in Ukraine is more than 20 years. In Poltava region, all main oil pipelines have been in operation for more than this period. Therefore, in the near future a significant part of the oil transportation system of Ukraine will exhaust its operational life.

One of the negative factors that increase the environmental risks of emergencies associated with soil, water and air pollution is external and internal corrosion processes of steel oil pipelines. Such scientists as O.E. Andreikov, Y.S. Gerasimenko, R.S. Grabovsky, I.M. Dmitrakh, A.Y. Zhdek, Y.L. Ivanitsky, A.V. Klimenko, E.I. Kryzhanivsky were engaged in general issues of ensuring the safety of operation, including the environmental safety of steel oil pipelines, Lobanov L.M., Nikiforchin G.M., Poberezhny L.Y., Skalsky V.R., Fedirko V.M. and others, but in their works insufficient attention was paid to the prevention of environmental pollution risks due to internal and external corrosion processes of steel oil pipelines. Understanding the laws of such processes and taking them into account is the scientific basis for determining the residual life of steel oil pipelines, as well as developing measures to prevent increased risks of environmental pollution during their operation. The development of scientific bases for ensuring the environmental safety of existing steel oil pipelines, which take into account the peculiarities and regularities of their electrochemical corrosion processes as a source of environmental pollution, is an urgent problem, the solution of which creates prerequisites for reducing the risks of environmental pollution during the operation of these facilities.

Idea of work is prevention of environmental pollution by oil products, products of their combustion or explosion as a result of internal and external corrosion processes of steel oil pipelines by means of the proposed methodology for assessing the residual resource of the specified oil pipelines.

II. LITERATURE ANALYSIS

Studying the oil transportation system of Ukraine, the authors of [1] noted that its reliable operation and safe operation is possible only with appropriate scientific and technical support. The problem of reliability should occupy a leading place in international and national legislation. Aspects of electrochemical corrosion and features of soil corrosion, corrosion conditions in different regions of Ukraine were studied by the authors [7]. In [2,4], the factors of reliability of oil pipelines and resources of the underground geological space of Ukraine, the process of corrosion of main oil pipelines in soil conditions, the problems of operation of underground facilities, the state of the linear part of the oil transportation system of Ukraine are investigated. The results of the research of scientists indicate the relevance of the research direction. Emergency situations arising from the destruction of sections of the oil transportation system of the state cause significant material and environmental losses.

The main role in assessing the environmental safety of operation in the presence of cracks in the insulation coating belongs to the study of the rate and depth of corrosion.

Known methods for assessing the state of metal based on the results of corrosion tests involve the use of quantitative indicators [5, 6]. The weight index of corrosion is

defined as the ratio of mass loss to the surface of the sample per unit time. The depth corrosion index is used in the assessment of both continuous and local corrosion. The volumetric corrosion index can be determined by the volume of gases released in relation to the surface of the sample for a certain period of time.

In the study of steel corrosion in concrete, electrochemical methods are used - measurements of potentials, currents, polarization curves, etc. An approximate assessment of the corrosion state of steel is given by the method of measuring polarization and the nature of the potential drop. The method is based on the relationship between the corrosion state of steel, the nature and rate of potential decline to the initial stationary value after external anodic polarization. If the steel is in a passive state, after disconnecting the polarizing current, the potential returns to a stationary value for a long time and vice versa, a rapid decline in potential indicates that the steel is in an active state.

The authors of [7] created special programs for computer calculations based on experimental data of metal corrosion rate.

Taking into account the fact that corrosion of steel with cracks is electrochemical in nature, recent developments in the calculation of corrosion losses are more focused on the use of electrochemical and electrical parameters, such as corrosion current density, electrode potential, polarization of metal in cracks, electrical resistance of the insulating coating. The advantage here is that these parameters can be obtained directly on the structures that are operated.

It is known from practical electrochemistry that the search for corrosion characteristics on metal in an electrolytic medium can be reduced to determining the distribution of electric potential and current on its surface [8, 9]. This makes it possible to use general approaches to calculating the steady-state electric field, which are developed in theoretical electrical engineering and sections of mathematical physics, in the study of corrosion of pipeline steel in cracks.

Much attention is paid to modeling the dependence of metal corrosion on environmental factors and predicting the durability of pipelines under corrosive influences in [10, 11]. One of the first models that describe the destruction of metal under the influence of an aggressive environment is Faraday's laws.

There are other mathematical models of pipeline metal destruction under the influence of the environment by other authors and scientists, but they are all somewhat similar and similar. This is manifested in the fact that the dependencies of the models are empirical in nature, include correction factors that are valid only for pipelines that are not subjected to local aggressive impact. Therefore, the above models do not allow to describe the processes of electrochemical corrosion of oil pipelines with sufficient accuracy.

Numerous studies on the behavior of steel in electrochemical corrosion are described in [12, 13], but the studies do not take into account the influence of local corrosion damage and operating conditions of structures.

Consequently, despite numerous studies, the need to develop new dependencies for assessing corrosion processes that would take into account local environmental influences and peculiarities of oil pipelines operation remains unexplored.

The study of the dependences of metal corrosion on environmental factors and the prediction of pipeline durability under corrosive influences, much attention was paid

in the works of Abdullin I.G., Gareev A.G., Gutman E.M., Ivantsov O.M., Novoselov V.F., Steklov O.I., Chernyaev K.V., Zikerman L.Y., Yasin E.M., etc. [17 - 23].

1. All corrosion models have the following dependencies:
2. Empirical dependences for calculation of corrosion losses of metals. The number of factors in the models does not exceed four.
3. Stochastic models in the form of regression equations (multifactorial models).
4. Mathematical multifactor models with a large number of "correction" factors that do not take into account (explicitly) the corrosion time and are based on purely "static" ideas about the kinetics of corrosion. They lack any graphical descriptions of corrosion kinetics as a function of time.
5. Models that are not expressed by a mathematical equation, but are presented as a set of tabular coefficients or nomograms recommended for assessing the corrosion state of metals (in certain aggressive environments).
6. "Cybernetic" models that capture the real causes of metal corrosion and are based on the accounting of such phenomena as the presence of internal feedbacks in the corrosion couple, which are an extremely important factor in the irreversible corrosion process. Such a model of corrosion pair allowed to obtain explicitly the best solution to the problem of predicting the future segment of the time series based on its statistical properties in the past, as well as to more accurately find the physical implementation of this solution.
7. Models of narrow purpose, for example, only for atmospheric corrosion of aluminum or underground corrosion of steel (in different soils).
8. Mathematical models based on the study of actual corrosion losses of metal.

For the first time the electrochemical nature of corrosion of metals in electrolyte solutions was proved in 1830 by the Swiss chemist De La Rive. He measured hydrogen release during the interaction of hydrochloric acid solution with zinc and its alloys with 10% Sn, Pb, Cu, Fe. He showed that the hydrogen release rates in this series are related as 1:9:18:43:54. It was the time when Englishman Faraday discovered the laws of electrolysis (1830-1833), he proposed the nomenclature: cation, anion, electrolyte.

Later, the electrochemical model of corrosion was developed by Soviet and domestic scientists L.V. Pisarzhevsky, N.A. Izgarishev, A.I. Brodsky, G.V. Akimov and others. So over time, a model of electrochemical corrosion was formed as the work of galvanic cells.

One of the first models that describe the destruction of metal under the influence of an aggressive environment is Faraday's laws.

P. Aziz, T. Champion, J. Metcalfe [24-26] proposed a nonlinear functional model of the corrosion process, which characterizes the dependence of the depth of the corrosion cavity on the aggressive environment and time:

$$\delta = k(1 - e^{\alpha t}), \tag{2.1}$$

where δ is the depth of the corrosion cavity, mm; k and α are coefficients characterizing the process of corrosion destruction; t is time, s.

When studying this dependence, it was found that the corrosion rate in the initial period increases, then becomes constant and finally decreases. Therefore, such a model with a long time is ineffective.

There are known models that define different variants of the power dependence of corrosion depth on time. They do not accurately describe the process of corrosion destruction and therefore are rarely used.

H. D. Tomashov to describe the corrosion destruction of metal used the dependence proposed by G. Tammann in 1920, which has the form [27]:

$$\delta = \sqrt{2kt}\,, \tag{2.2}$$

where δ is the thickness of the oxide film; k is a coefficient that depends on the diffusion coefficient and oxygen concentration; t is time, s.

This model takes into account only one factor - the supply of oxygen to the metal.

Y. P. Shturman proposed a model for soil corrosion of metal in the form of a fractional linear function [28]:

$$\delta_k = \frac{\delta_0 \cdot t}{T + t}. \tag{2.3}$$

where δk is the depth of the cavity; δ0, T are constant values that characterize the properties of the metal and the environment; t is time, s.

The graphical dependence shows that metal losses become constant over time.

The work of Yu. N. Mikhailovsky tried to establish empirical correlations between the average monthly rate of atmospheric corrosion and monthly precipitation, the number of rainy days per month, the number of days with relative humidity above 80%. The paper points out that it is impossible to derive a single empirical equation that would relate the corrosion rate to known environmental parameters. Therefore, from all the parameters that affect the rate of atmospheric corrosion, several combinations were made. Dividing the experimental data into several groups, the authors obtained six functions that depend on five parameters [29].

In the works of A. S. Koryakov, V. V. Phillipov, the equation of corrosion wear of the pipeline is also given by the differential equation [30]:

$$\frac{d\delta}{dt} = k(1 + \alpha\sigma)\cdot\delta(b - \delta). \tag{2.4}$$

where δ is the value of corrosion wear of the element; t is time; α, b, k are empirical coefficients; σ is the value of internal loads.

However, cases are allowed when b(σ)=const.

There are other mathematical models of pipeline metal destruction under the influence of the environment by other authors and scientists, but all of them are somewhat similar and similar. This is manifested in the fact that the dependence of the models includes many different correction factors that take into account the influence of only some environmental factors and are valid only for pipelines that are not subject to local aggressive impact. Therefore, the above models do not allow to describe the processes of electrochemical corrosion of oil pipelines with sufficient accuracy.

Therefore, the need to develop new models and dependencies that would take into account environmental influences, including local ones, peculiarities of oil pipeline operation and other possible factors, does not lose its relevance, despite numerous studies.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The aim of the work is to develop dependences for calculating the depth of corrosion of the wall of an underground steel pipeline in the crack of the insulation

coating under the action of an electrolytic medium aggressive towards the metal of the pipeline.

To achieve this goal, the following tasks were solved:

-to develop a physical and mathematical model of electrochemical corrosion of a steel pipe section in the cracks of the insulating coating of structures under the influence of aggressive electrolytic solutions, which would be based on real parameters obtained by non-destructive testing of structures;

-to develop a dependence for calculation of corrosion depth of the wall of underground steel pipeline in the crack of the insulating coating under the action of aggressive electrolytic medium in relation to the pipeline metal.

Object of research - the process of electrochemical corrosion of steel pipeline with damaged insulation coating.

Subject of research - a pipeline with cracks in the insulation coating, operated in an electrolytic environment aggressive to the steel pipe.

Research methods:

Analytical - in the development of a mathematical model of the galvanic corrosion element, in the calculation of losses of the pipeline cross-section at a constant presence of aggressive fluid in the crack of the coating, in the development of dependencies for calculating the loss of the relative cross-sectional area of the pipeline wall, Experimental - in the study of losses of the pipeline cross-section at local corrosion.

The scientific novelty of the obtained results is as follows:

-the mathematical model of the macrogalvanic pair operation at local corrosion of the pipeline section was further developed, the calculations on which allow predicting corrosion losses of the pipeline metal in the cracks of the insulating coating when aggressive electrolytic solutions get into them, regardless of their chemical composition;

-for the first time the mathematical model of macrogalvanic pair operation at local corrosion of the pipeline section was investigated**.**

IV. RESULTS

IV.I Analysis of soil conditions of oil pipelines operation in Poltava region

Oil pipelines are operated in the soil, the conditions of which are characterized by heterogeneity and are determined by various factors. Corrosion activity of soils for underground pipelines is determined according to GOST 9.602-2005 "Underground structures. General requirements for corrosion protection". Main oil pipelines are operated in natural conditions, mainly underground, so they are subject to underground soil corrosion. The study of corrosion properties of the soil environment, in which the oil pipelines of Ukraine, in particular of Poltava region, are operated, is especially relevant, since the network of oil pipelines is extensive, and the soils in which they lie are diverse in their type, mechanical composition and other indicators.

On the basis of monitoring and scientific and technical literature data, the analysis of soils of Poltava region along the main routes of oil pipelines for their corrosion activity

according to the following indicators: mechanical composition of the soil, moisture, humus content, chlorides, sulfates, nitrates, electrical conductivity of the soil, etc.

Based on the data obtained, maps of soil corrosion activity by districts of the region and indicators affecting soil aggressiveness were constructed (fig. 1a, b).

The influence of aggressive solutions of the soil environment on the areas of damage to the insulating coatings of steel oil pipelines, as well as on the course of corrosion processes, was revealed, maps of soils by indicators of their corrosion activity were built on the example of Poltava region. It is established that the properties of soils in Poltava region contribute to the emergence and development of corrosion processes on the outer surfaces of oil pipelines, which significantly increases the likelihood of environmental pollution due to depressurization of steel oil pipelines.

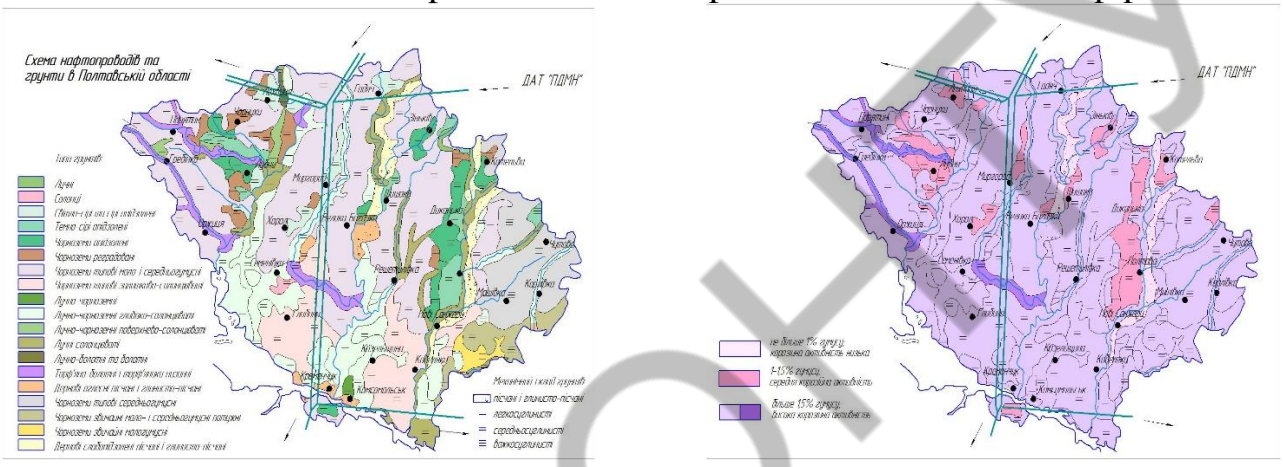

Fig. 1 Maps of corrosion activity of soils in Poltava region with regard to type and mechanical composition (a) and average humus content (b)

Thus, in Poltava region there are all conditions for the development and course of corrosion processes in the outer sections of oil pipelines, since the oil pipelines of Poltava region have a significant length and are operated in environments characterized by a variety of edaphic indicators, which significantly affects their environmental safety.

Thus, having examined the soils in which the oil and gas pipelines are operated in Poltava region, there is every reason to believe that there are all conditions for the formation and course of electrochemical corrosion in the areas of underground transport facilities.

IV.II Modeling of local corrosion element on the section of steel pipeline

The issue in question is of special importance in regard of oil pipelines operated with the sections in which there is damage in pipeline insulation caused by their exposure to electrolytic solutions. These areas greatly influence the development of pipeline corrosion, creating conditions for the occurrence of macro-corrosion couples. In the underground pipelines with sections with a damaged insulation, the anode and cathode polarizing characteristics of steel significantly change and, as a result, potentials of steel in these places. Given the fact that the operation of an oil pipeline with sections with damaged insulation is associated with electrochemical corrosion of pipeline metal, special attention during inspection of the pipeline should be paid to

determining the characteristics of corrosion process. Current of the given galvanic couples is a universal indicator for calculating the loss of metal in the fractures.

Insulation coating as a capillary-porous material is the conductor of type 2, which is why the process of steel corrosion in it can be considered from the standpoint of typical electrochemical corrosion of metals in electrolytes.

A theory of metal corrosion considers two ways in which the electrochemical corrosion proceeds – homogeneous and heterogeneous. Most cases, which include the corrosion of pipeline in a fracture, are dominated by the heterogeneous mechanism of metal destruction. In this case, some areas at the surface of metal are the cathodes (pipeline under a layer of insulation) while the others are the anodes (pipeline in a fracture).

In this statement, a problem on electrochemical corrosion of the section in a pipeline comes down to determining the stationary electric field that occurs at galvanic couple work on the heterogeneous electrode. In other words, to recording the equations and formulas of boundary conditions that are satisfied by the potential of this field.

The basic characteristic of electric field is the potential by which one may find the density of corrosion current by the known Ohm's law in differential form:

$$i = -\gamma\left(\frac{d\varphi}{dy}\right)_{y=0} \qquad (4.1)$$

where γ is the electrical conductivity of electrolytic environment; N is the normal to the surface of corroded metal; φ is the potential.

Consider the electric field near a heterogeneous electrode whose model consists of 2 sections of arbitrary width, which are different in stationary potentials [2]. A local corrosion element is represented by the section of pipeline under an insulation coating (the cathode) and the section of pipeline in the fracture under the electrolyte (the anode) (Fig. 2).

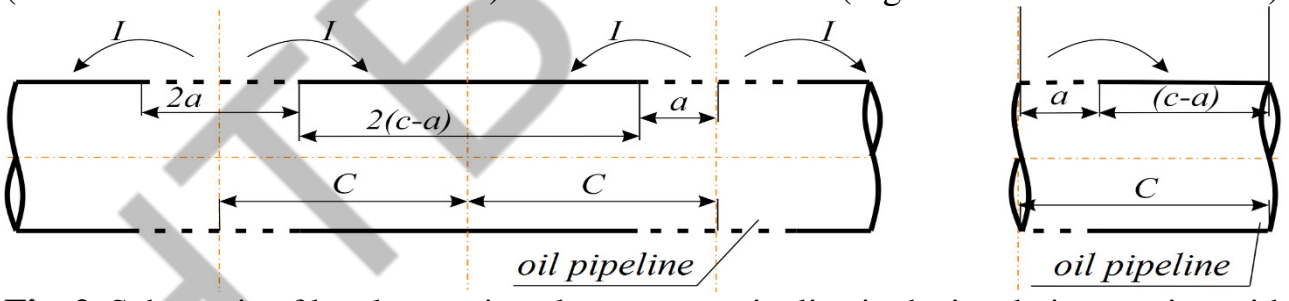

Fig. 2. Schematic of local corrosion element on a pipeline in the insulation coating with a fracture: *a* – general view; *b* – estimated model, *c* – distance between the midpoints of sections; 2*a* – width of the anode section; 2 (*c*-*a*) – width of the cathode section; 1– pipeline; 2 – insulation coating; 3 – fracture; 4 – electrolytic medium(aggressive fluid).

Due to the symmetry of the model of non-uniform surface, it is sufficient to consider not the entire surface, but only part of it, between marks x=0 and x=c, which correspond to the midpoints of heterogeneous areas, and point a is the boundary between them. This part of the surface of the pipeline is from now on considered to be a local corrosion element.

Determining the distribution of electric field potential in this case can be reduced to the solution of a two-dimensional Laplace equation:

$$\frac{\partial^2\varphi}{\partial x^2}+\frac{\partial^2\varphi}{\partial y^2}=0, \quad (4.2)$$

where φ is the potential; x, y are the flow coordinates.

Boundary conditions are as follows:

1) there are no any excitations in an electric field at infinite distance from the surface of the electrode (pipeline): φ (y→∞, x)=const;

2) the second is the consequence of the considered model: $\frac{\partial\varphi}{\partial x}|_{x=o}=\frac{\partial\varphi}{\partial x}|_{x=c}=0;$

3) conditions on the heterogeneous sections will be represented in the form:

$\varphi=E_a+Ld\varphi/dy$ at y=0, 0≤x<a;

$\varphi=E_c+Ld\varphi/dy$ at y=0, a≤x<c;

where $L=\gamma\cdot b$; γ is the specific electric conductivity of electrolyte; b is the coefficient of polarization; E_a, E_c are the current-less potentials of anode and cathode, mV.

Solution of equation (4.2) at such boundary conditions can be obtained by the Euler-Fourier method. The task is to find these functions. As a result of long transformations, we receive:

$$\phi(x,y)=\frac{a(E_a-E_K)+cE_K}{c}+\sum_{K=1}^{\infty}\frac{2(E_a-E_K)}{\pi k\left(1+\frac{\pi k}{c}L\right)}sin\frac{\pi k}{c}a\,cos\frac{\pi k}{c}xe^{-\frac{\pi k}{c}y}= \quad (3)$$

$$=\frac{a(E_a-E_K)+cE_K}{c}+\frac{2(E_a-E_K)}{\pi}\sum_{K=1}^{\infty}\frac{sin\frac{\pi k}{c}a}{\left(1+\frac{\pi k}{c}L\right)k}cos\frac{\pi k}{c}xe^{-\frac{\pi k}{c}y}.$$

with regard to $i=-\gamma\left(\frac{d\varphi}{dy}\right)_{y=0}$ we obtain equation for determining the distribution of current density along the surface of one of the local element:

$$i(x)=\frac{2(E_a-E_k)\gamma}{c}\sum_{k=1}^{\infty}k\frac{\sin\frac{\pi ka}{c}\cos\frac{\pi kx}{c}}{k(1+\frac{\pi kl}{c})} \quad (4.3)$$

Thus, we solved the problem on modeling the electrochemical corrosion of steel in a fracture of the insulating coating under the action of electrolytic medium, aggressive to metal, which comes down to determining a stationary electric field of the heterogeneous electrode. The benefit of this model is the possibility to predict the development of corrosion of reinforcement over time, which is important when determining the residual resource of a reinforced concrete structure.

IV.III Calculation and experimental verification of the thinning of the pipeline wall at the operation of the galvanic corrosion element in the crack of the insulating coating

Once the fact of coating failure is established, the question of predicting the time of leakage due to pipe corrosion arises. Quantification of corrosion losses depends on the loss of cross-sectional area of the pipeline surface.

To calculate the decrease in wall thickness when an aggressive electrolytic solution is permanently present in the zone of damaged insulation, the dynamics of the

corrosion depth of the pipeline during the operation of the galvanic element "pipeline with damaged insulation - pipeline under an insulating coating" was considered. It is assumed that the local corrosion ulcer has a round shape. Consider a corrosion ulcer on a pipe in the form of an equilateral cone that grows evenly. The mass of lost metal of the pipeline will be numerically equal to the volume of this cone, taking into account the specific gravity of the metal. Suppose that in the last phase the outer diameter of the corrosion ulcer is equal to the thickness of the pipe wall or the depth h of the ulcer.

$$h = \frac{V}{\pi D_0 a_y} = \frac{KIt}{7{,}87\pi D_0 a_y}, \tag{4.4}$$

where V is the volume of corroded metal, cm^3; D0 is the initial thickness of the pipeline wall, cm, K is the electrochemical equivalent, g/A h; t is the corrosion time, hours; 7.87 is the specific gravity of the pipeline metal, g/cm^3; I is the galvanocouple current, A; a is the length of the pipeline section with the damaged insulation coating to be affected.

Taking into account the electrochemical corrosion current of the macrogalvanocouple, an expression for determining the depth of corrosion lesions was obtained.

$$h = \frac{K}{7{,}87\pi D_0 a_y}\left(\frac{2(E_a - E_k)\gamma}{\pi} \times \sum_{\kappa=1}^{\infty} \frac{1-\cos 2\frac{\pi k\alpha}{c}}{\frac{2}{\kappa(1+\frac{\kappa\pi L}{c})}}\right)t. \tag{4.5}$$

In order to experimentally verify the proposed methodology for calculating the corrosion depth of the pipeline wall when the galvanocoupler is operating in soil conditions, a study was conducted on small samples of 18G2AFps steel.

10 sample elements of steel cylinders with a thickness of 1 and 6 mm were prepared. The insulated steel samples have outlets on one side, they modeled the pipeline in the crack of the insulating coating. Samples with a thickness of 6 mm have outlets on the surface of soldered insulated cold-drawn wire. Before isolation, the samples were cleaned and weighed on an analytical balance. In order to study the corrosion losses of steel during the operation of macrogalvanocouples, in the course of the experiment, a device was created, which consisted of a plastic container filled with an aggressive liquid, and prepared samples half-immersed in the liquid. A 3% NaCl solution, which is a standard electrolyte in electrochemical studies of metal corrosion, was chosen as an aggressive environment for accelerating corrosion.

Each sample was immersed in the solution for half of its thickness with the calculation that the exposed issues of the samples were in the aggressive solution. Incomplete submersion of the test samples allows creating a differential aeration galvanocouple on the pipe with anodes on the exposed sample outlets and cathodes on the sections of the pipe in the insulation, which reflects the real conditions when the steel of the oil pipeline is moistened in the crack of the insulation coating. After the experiments, the elements of the steel samples were released from the insulation,

cleaned and weighed. The weight index of corrosion was determined by the difference in weight before and after corrosion studies.

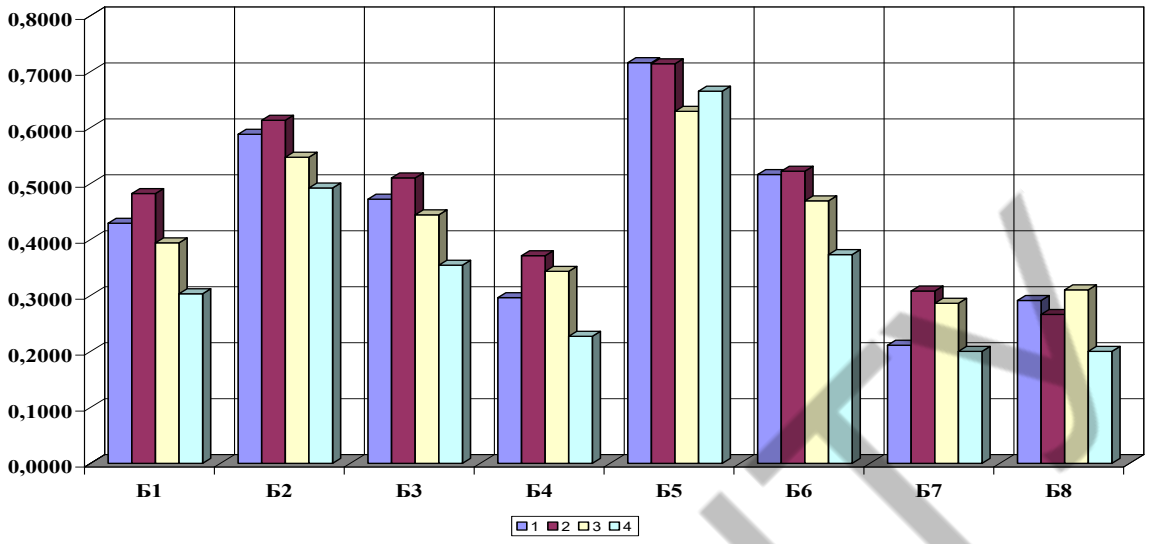

Fig. 3. Comparative diagram of loss of relative cross-sectional area on samples during corrosion: by the calculated value of current ν_p; by weight indicators ν_e; by depth indicators ν_h; by direct measurements of diameters ν_d.

Thus, it can be seen from the results of experimental studies on the corrosion of steel samples under the conditions of the formation of galvanic pairs that they coincide quite well with the data obtained during calculations based on the developed mathematical model

The determination of the residual resource of the oil pipeline by the steel corrosion factor in the crack of the insulating coating is carried out by taking into account the decrease in the thickness of the wall of the oil pipeline, which is entered into the calculation.

V. CONCLUSIONS

Taking into account the fact that the operation of oil pipelines with areas where the insulation is broken is associated with electrochemical corrosion of the pipeline metal, the main attention to ensure the environmental safety of the pipeline operation should be paid to the determination of corrosion losses on the pipeline in places of insulation failure due to the operation of the corrosion element. The solution of the issues of timely detection of corrosion and determination of its rate and zone of spread will help to prevent the creation of emergency situations on the pipeline and ensure the environmental safety of its operation.

As a result of the scientific work, the following conclusions were obtained:
The problem of modeling the electrochemical corrosion of the pipeline in the crack of the insulating coating under the action of an electrolytic medium aggressive to the metal of the pipeline is solved, which is reduced to the determination of the stationary electric field arising during the operation of a macrogalvanocouple with an anode on the pipeline in the crack and a cathode on the pipeline under the insulating coating. The advantage of this model is the possibility of predicting the development of corrosion in time regardless of the chemical composition of the aggressive electrolyte, the

possibility of obtaining the necessary design parameters on the structures in operation in a non-destructive way.

2. The dependence, which allows to calculate the depth of corrosion and relative loss of cross-sectional area of reinforcing rod in the crack of reinforced concrete structure during the operation of macrogalvanic corrosion pairs and the constant presence of aggressive solution in the crack, was obtained.

3. Experimental studies on small samples of the methods for calculating the relative loss of cross-sectional area of the pipeline during corrosion in a crack in a solution of 3% NaCl showed that direct corrosion tests are consistent with the calculated values of the macrogalvanic corrosion pair current

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IMPLEMENTATION OF GREEN TECHNOLOGIES IN RIVER TRANSPORT

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Abstract. *The object of follow-up is Ukrainian river transport.*

The subject of the research is the officials of river transport for the ecological safety of dovkil.

Meta work - analysis of the European version of models for the development of transport infrastructure, analysis of recommendations and solutions to problems, analysis of the regulatory framework for the implementation of green technologies in river transport and the impact on the quality of the human environment and the health of the population.

The method of follow-up is deep science, theoretical, empirical and special.

In the work of conducting an analysis of the regulatory and legal framework for some promising directions for the promotion of green technologies in river transport, injecting river transport into dovil in the borders of Ukraine, the current state of the country was developed for the help of deep science, theoretical methods.

For the help of empirical methods and special methods, the main criteria for the development of alternative transport transportations were determined. Detailed recommendations from the improvement of river transport, modernization and implementation of green technologies on river transport, green spaces in the borders of megacities of Ukraine and analysis of the removal of data.

Keywords: *hybrid vessels, river fleet of ukraine, eu waterways, modernization, demand of the netherlands.*

1. INTRODUCTION

Environmental pollution by water transport occurs in two ways: firstly, sea and river vessels pollute the biosphere with waste from operational activities and, secondly, emissions in cases of ship accidents with toxic cargoes, mostly oil and petroleum products.

Under normal operating conditions, the main sources of environmental pollution are the ship's engines, primarily the main power plant, as well as water used for washing cargo tanks and ballast water discharged overboard from cargo tanks.

The atmosphere is polluted with exhaust gases from power plants of ships, through which toxic substances partially or almost completely enter the waters of seas, rivers and oceans. The majority of modern ships of the domestic and world fleet are equipped with diesel engines. And a very small share today is made up of vessels with

steam turbines, moreover, the number of which has been decreasing in recent years due to the fact that they are less economically profitable compared to diesel engines. Today, the number of vessels with gas turbine installations is one.

Oil and petroleum products are among the main pollutants of the water basin during the operation of water transport.The negative impact of water transport on the hydrosphere is due to the fact that on tankers that transport oil and its derivatives, before each subsequent loading, containers (tanks) are usually washed to remove the remains of previously transported cargo. Wash water, and with it the remains of the cargo, were usually dumped overboard. In addition, after the delivery of oil cargoes to the ports of destination, tankers, as a rule, are sent to the point of new loading without cargo. In this case, to ensure proper draft and safe navigation, the oil tanks of the ship are filled with ballast water, which leads to contamination with oil residues. Therefore, the efforts of scientists and designers are aimed at creating effective means of cleaning the washing and ballast water of oil tankers. The relevance of work in this direction is confirmed by the rapid development of the tanker fleet, which is due to the development of industry and the growth in the consumption of oil and oil products derived from it, which, in turn, leads to an increase in the need for oil transportation. About 49% (1984) of the total cargo turnover of the world marine fleet is oil and oil products (65.5% in 1977), and 72% in 2020.

Thus, in a first approximation, ecological damage to the aquatic environment can be calculated as the sum of losses from sulfur dioxide, nitrogen oxides, soot and emissions of unburned fuel from ship engines, as well as evaporation of oil cargoes of the transport fleet.

An important role in the protection of the natural environment can be played by the conversion of coastal vessels and the port fleet to natural gas and the use of hydrogen from hydride batteries for liquid fuel. For this purpose, it is necessary to carry out a set of measures, which would include the issue of disposal of vapors of liquid residues of oil tankers to ensure economic operation. Utilization of vapors from oil cargoes is one of the effective environmental protection measures. Today, a large group of chemists, technologists and engineers around the world are working on this very question. In addition, it is necessary to pay special attention to the equipment of offshore drilling platforms with gas turbine generators.

The environmental situation in the world is steadily deteriorating, and it forces a new assessment of the directions and prospects of the development of SEU, energy schemes used in ship installations, and their operation modes.Modern scientists and engineers of many countries of the world have already changed their attitude to the use of high-sulfur heavy types of fuel in ship power generation due to the fact that the amount of sulfur oxides in the exhaust gases is directly proportional to the sulfur content in the fuel. We can hope that in the coming years priority will be given to such installations, in which the harmful impact on the environment will be minimal due to high energy efficiency.

It should be noted that the private sector of the economy should also play an important role in the revival of the inland water transport sector. The government, in turn, must ensure the proper functioning of public infrastructure, which includes well-functioning shipping locks, shipping fairways with a minimum guaranteed depth,

navigational aids and a modern water traffic management information system. One of the main tasks of the development of this type of transport lies with the private sector of shipping today - it is necessary to build a new fleet and carry out cargo transportation on the rivers of Ukraine. Cargo owners, exporters and shippers need to use river transport as much as possible in their logistics chains, which is both economically and environmentally beneficial for our society and the state as a whole.

If such an approach can be implemented, by 2030 it will be possible to transport up to 35 million tons of cargo through the river network of Ukraine, while now we have the ability to transport only 12 million tons.Pollution of Ukrainian rivers, in particular the Dnipro River, is a serious problem of our country, which must be urgently solved. The Dnipro is of great importance for the entire country not only because it is a significant source of drinking water for the population. It is also a generator of electricity thanks to hydroelectric power plants and is used for the transportation of goods and passengers, for industries, for the agricultural sector, for leisure, because people like to swim, swim and fish from a boat.

In addition, an incentive program for the construction of very low-emission ships should be created to have a zero-emission fleet by 2050.

The strategy also provides for the creation of a sufficient number of bases and the necessary equipment for the rapid cleaning of hazardous materials that may enter the water as a result of an accident.The purpose of the work is to analyze the European experience of transport infrastructure development models, to develop recommendations for solving the problems of analyzing the regulatory and legal basis for the introduction of green technologies in river transport and its impact on the quality of the urban environment and the health of the population.

The main tasks solved in the work include:

– identify the main polluting substances of transport;

– consider the specifics of the impact of transport on the environment;

The object of the study is river transport of Ukraine.

The subject of the study is the factors of influence of river transport on the ecological safety of the environment.

The research method is general scientific, theoretical, empirical and special.

1. STATUS OF INLAND RIVER NAVIGATION AND "GREEN" ALTERNATIVE USE

Ukraine is starting to gradually revive river navigation. The Verkhovna Rada adopted the basic law for inland water transport, which should set the course for the strategic development of the industry. However, the existing unsatisfactory state of river navigation makes the revival of the national river economy a difficult task.

There are a number of problematic issues that hold back the growth of transportation by inland water transport in Ukraine, which require an urgent solution:

1) imperfect, outdated, missing and underdeveloped infrastructure, namely: locks, navigation, overall and vessel passage, i.e. everything that hinders effective logistics, including the full participation of IVT in multimodal transportation.

2) there is no sufficient private infrastructure, namely: terminal complexes, multimodal logistics centers, etc.

3) aging and shortage of modern cargo and technical fleet.

4) lack of systematic personnel policy and lack of qualified personnel on inland waterways.

5) the imperfection of the legislation, which does not provide clear regulation, creates an excessive bureaucratic burden and prevents the creation of an attractive investment climate.

6) the absence of a law on inland water transport and, accordingly, the absence of a sustainable financing mechanism for the industry.

7) lack of integral, systematic state management of the industry.

8) non-competitive working conditions compared to other modes of transport, in particular excessive tax burden and lack of guaranteed budget funding. Lack of clear division of responsibility for maintenance and development of inland waterways, duplication of functions between executive authorities.

Back in 2016, the Embassy of the Netherlands announced the Dnipro Development Initiative, which was supported by the European Union and all major donors of Ukraine. Since 2016, significant funds have been invested in the study of river transport problems and ways to overcome them. The truth is that all these efforts of international partners were not enough for the adoption of the reform in 2018.

After the failure of the reform vote in 2018, at the initiative of the EBRD, a series of round tables was organized with representatives of the Nibulon company, the parliament, the Ministry of Infrastructure, the European Commission and all involved donors to find possible options for the implementation and promotion of this reform. As a compromise, the draft law excluded regulations regarding the collection of river tolls, the creation of new enterprises for the maintenance of inland waterways, and the granting of rights to carry out cabotage transportation on the river by vessels flying the flag of foreign states.Based on the results of the round table, the Transport Committee of the Verkhovna Rada of Ukraine together with the Ministry of Infrastructure, international partners from the World Bank, EU, EBRD, EIB, the US government and the Embassy of the Netherlands in Ukraine developed a draft law "On Inland Water Transport", which was registered on July 9, 2018 year under No. 2475 a-d. This bill is currently a compromise for all interested parties.

As a result of the unsatisfactory technical condition of the locks, which have practically exhausted the maximum service life of 70 years, as well as due to the long-term underfunding of the maintenance of the Dnipro river navigation locks, which in recent years did not exceed 50% of the necessary need, a situation has arisen that carries a real threat of the occurrence of man-made disasters. The actual operating life of the reservoirs varies from 27 years (Dnistrovsk) to 67 years (Dniprovske). According to the indicator of the level of exploitation of the useful area of reservoirs, the Kremenchutsk (65.9%) and Dnistrovsk reservoirs (66.7%) are most efficiently exploited. The rest of the reservoirs are exploited only at a third of their capacity (Kakhovskoe – 37.4%; Kyivske – 32.2%; Dniprovske – 30%) and even less – Dniprodzerzhynske – 12.5%, Kanivske – 11.5%.

Another significant problem is that the available potential of the river fleet is decreasing due to the approach of a significant part of it to the critical period of operation.Today, technically and morally outdated vessels are used in river transport, with an average age of operation from 21 to 25 years, which is almost 82% of the entire river fleet of Ukraine. In the structure of the transport fleet, the largest share of obsolete vessels is cargo-passenger vessels - 97.1%; bulk cargo vessels – 89.5% and dry cargo vessels – 84.4%. Among the special-purpose vessels, the largest share is made up of raiding and maneuvering, towing and roving vessels - 90.7%, technical vessels - 79.6% and service and auxiliary vessels - 77.7%. The share of the fleet suitable for operation today is only 80.8%, i.e. 1,648 units, and the fleet unsuitable for operation is 19.2%, i.e. 392 units.

The available potential of the operable river fleet consists of vessels with a gross capacity of 1,853.8 thousand cubic meters. meters, carrying capacity – 922.6 thousand tons, deadweight – 951.9 thousand tons, power 293.4 thousand kW, and passenger capacity – 17.2 thousand passengers. Among them: service and auxiliary vessels – 46.7%, i.e. 770 units, transport vessels – 44.4%, i.e. 731 units, technical vessels – 6.9%, i.e. 113 units and special purpose vessels – 2.1%, i.e. 34 units.

Transport vessels have a total carrying capacity of 899.8 thousand tons, deadweight - 891.9 thousand tons, power - 109.4 thousand kW and passenger capacity - 16.4 thousand passengers. These are cargo bulk vessels - 38 units; dry cargo ships - 590 units; passenger and cargo-passenger vessels – 103 units. The "river-sea" transport vessels belong to the most famous shipping companies, such as: Joint-Stock Shipping Company (JSC) "Ukrrichflot", Private Joint-Stock Company "Ukrainian Danube Shipping Company" (PJSC "UDP"); KDM ShippingPublicLtd. (Cyprus) - to the holding company of the shipping operator "Stolichna Ustuplavna Kompany" LLC (Kyiv), as well as to the agro-industrial group of LLC "NIBULON" JV.

An integral part of the use of the river transport potential of Ukraine should be the expansion of the network of multimodal transportation by vessels of the "river-sea" type and the construction of the national river fleet with the involvement of domestic production capacities. Work in these areas will make it possible to increase the competitiveness of inland water transport (IWT) and the national transport system of Ukraine as a whole, as well as to fulfill the obligations that will correspond to the Agreement on the Association of Ukraine and the European Union.

In the last ten years, river transport has been actively developed as a priority mode of transportation in the European Union in view of the need to achieve such global strategic goals as reducing the energy dependence of the economies of EU member states and reducing greenhouse gas emissions into the atmosphere, as well as ensuring the competitiveness of the European transport system and a high level of mobility. By signing the Association Agreement with the EU, Ukraine assumed a number of obligations regarding the development of IVT, in particular regarding the development in cooperation with the European Union of a strategy for the development of river transport based on the national transport policy, the inclusion of river transport in the system of multimodal transportation and a network of priority transport routes , implementation of the norms of European law in the field of inland water transport to

the national legislation. In particular, the Agreement, which provides for Ukraine's implementation of the following EU directives:

- on the functioning of the transportation market - Council Directive No. 96/75/EC on chartering and pricing systems for national and international inland waterway transport of the Community;

- access to the profession - Council Directive No. 87/540/EEC on access to the carriage of goods by waterways for national and international transport and on mutual recognition of diplomas, certificates and other official certificates of qualification for such activities, Council Directive No. 96/50/ EU on harmonization of conditions for obtaining national certificates of captains for the transportation of passengers and cargo by inland waterways within the Community;

- transportation safety - Directive No. 2006/87/EU of the European Parliament and Council dated 12.12.2006 establishes technical requirements for vessels on inland waterways; Directive No. 2008/68/EU of the European Parliament and the Council of 24.09.2008 regarding the transportation of dangerous goods by internal roads;

Taking into account the above, for the revival of shipping in Ukraine on inland waterways, increasing the efficiency of using the potential of river transport as an alternative ecological mode of transportation, the implementation of European norms and standards regarding the functioning and development of river transport.

2. IMPROVEMENT OF THE MONITORING SYSTEM OF HARMFUL EMISSIONS INTO THE ENVIRONMENT

Atmospheric air pollution is one of the most urgent environmental problems of our time, as the level of pollution increases every year, which leads to negative consequences not only for the ecosystem, but also for human health and life. Atmospheric pollution occurs as a result of emissions of harmful substances into the atmosphere from stationary and mobile sources.

Today, the governments of many countries and many companies are working on programs and developing environmental initiatives that are directly aimed at reducing environmental pollution and emissions of harmful substances into the atmosphere by conducting environmental control over business.

The subject of ecological monitoring is the organization and functioning of the system of monitoring, assessment and forecasting of ecological systems and their elements, the biosphere, the nature of the influence of natural and anthropogenic factors on them.

The object of monitoring according to the level and purpose of environmental research is the environment, its elements and sources of influence on it, in particular atmospheric air, underground and surface waters, soils, waste, adverse natural processes (landslides, karst, etc.).National ecological monitoring of the environment is a system of observation, collection, processing, transmission, storage and analysis of information about the state of the environment, its forecasting, changes and development of scientifically based recommendations for making management decisions.

Thus, the modern system of monitoring parameters and the state of the environment needs to be modernized and improved in order to ensure the effective integration of Ukraine into the European Union. In order to effectively and fully perform the functions of the state system, environmental monitoring must be based on predetermined regulatory requirements regarding the responsibility of business entities, justifications for monitoring programs, as well as environmental safety requirements. The need to combat CO2 emissions and improve the efficiency of fuel use in the transport sector is obvious, in particular due to:

– use of innovative transport technologies, advanced engine control systems and efficient power units;

- the use of sustainable biofuels and not only the first generation (vegetable oil, biodiesel, bioalcohols and biogas from sugar factories, agricultural crops or animal fats, etc.), but also the second (biofuel from biomass, non-food plants, wood) and the third generation (fuel from algae microorganisms , which is completely decomposed);

– improvement of transport infrastructure together with Intelligent Transport Systems (ITS) to prevent congestion on transport routes and promote the use of intermodal transport (road, rail and water);

– the use of legal instruments (such as tax incentives for low-carbon products, taxation of CO2-intensive products and processes, etc.).

Figure 1 – Schematic view of the environmental monitoring system

The increase in the volume of transportation, which is mainly carried out by motor vehicles, significantly complicates the transport situation in Ukraine, and is characterized by the following aspects:

– a significant negative impact on ecosystems and public health due to atmospheric pollution by TK emissions;

– excessive consumption of extractable non-renewable fuel and, accordingly, the growth of greenhouse gas (CO2) emissions into the atmosphere;

- the use of large areas of land for the construction of transport infrastructure facilities.

In 24 large cities of Ukraine, especially in Kyiv, Kharkiv and Odesa, harmful emissions into the atmosphere due to the operation of vehicles exceed 50% of their total amount.

Maritime transport pollutes the sea with food waste, garbage, oil and oil products, which cannot but negatively affect the ecological state of the seas, especially in port areas.

Considerable attention is paid to the control and monitoring of atmospheric air in the countries of the European Union, the USA, Japan and other developed countries. Among them, such systems as EAPMS, ISIREMM, SOSE, TAPM, OND-86 should be noted.Для оцінювання забруднення навколишнього середовища та ідентифікації економічно ефективних заходів щодо подальшого поліпшення якості повітря у світі Міжнародним інститутом прикладного системного аналізу IIASA у 1984 році було розроблено модель RAINS(The «Regional Air Pollution INformation and Simulation» (Simulation and information on regional air pollution).

Analysis of the current environmental monitoring system in Ukraine shows that it has not yet become an important tool for effective management of environmental quality, timely prevention of harmful effects of pollutants on air, water, soil, health and well-being of the population, as well as wide public awareness of state and trends of environmental changes. The current system of state monitoring only partially provides accurate and reliable quantitative information on the flow levels of harmful or potentially harmful substances in the surrounding natural environment. For the current monitoring system, the initiation of management measures to protect, preserve and restore the quality of the natural environment, etc., has not become the main purpose.

3. NEW TRANSPORT STRATEGY OF THE EU

The European Union is laying the groundwork for how its transport system can achieve its green and digital transformation and become more resilient to future crises. Thanks to a smart, safe and accessible transport system, the EU wants to reduce emissions by 90% by 2050.

Environmental problems are becoming increasingly important for society. Social, political and economic requirements are introduced for the sustainable development of transport, which involves reducing the impact of the entire supply chain on the environment. There is a strong interaction between logistics, environmental protection and natural resources. Climate change and environmental degradation are a vital threat to Europe and the world, therefore, in order to stimulate the development of the economy, improve the health and quality of life of people, as well as to transform climate and environmental challenges into opportunities in all areas and policies of the EU, the European Green was created Course.The European Green Deal is a road map of measures that will transform the European Union into an efficient, sustainable and competitive economy, determine the means of transforming Europe into the world's first climate-neutral continent by 2050, stimulating economic development, improving health and quality of life people, and transform climate and environmental challenges into opportunities in all areas and EU policies, ensuring a fair and inclusive green transition.

Transport in the logistics system plays a dual role:

– it is a component or component of the main functional branches of logistics (purchasing, production, distribution);

- transport is one of the branches of the economy, in which entrepreneurial activity also develops: transport offers its products on the market of goods and services - transport services for which it receives income and has a profit. Ukraine has significant potential for the use of less harmful modes of transport, as one of the longest railway networks in Europe is located on its territory, and there is a wide network of inland waterways with access to the sea. However, the low quality of Ukraine's transport infrastructure, which is present in all its components, becomes a significant obstacle to the use of more ecological transport. The situation is complicated by insufficient interaction between different branches of the transport sector, low investment inflow, an outdated regulatory system and a high degree of wear and tear of fixed assets;

– formation of an effective system of ecologically oriented logistics management of industrial production based on the application of innovative management methods and tools;

- ensuring the adaptability of the logistics system to the changing conditions of the external environment. 2.3 Methods of reducing the impact of water transport and negative impact on the environment

Water transport transports goods and passengers on both natural and artificial waterways, and is divided into sea and river.

Maritime transport is a type of transport sector of material production that transports goods and passengers by sea vessels. Sea transport is widely used for international and domestic transportation.

Today, there are three main directions for cleaning polluted waters of seas and rivers. With the mechanical method (Fig. 1.3), large floating units perform operations of varying degrees of complexity - from simple collection of floating debris from the surface to catching and separating oil products. Collected garbage and oil-containing waters are sent to shore stations for disposal and disposal.

In the practice of work of seaports of Ukraine, boom barriers have been used. They are installed for preventive purposes around tankers that are being unloaded or loaded, as well as to protect vessels receiving fuel.

In many countries, physical and chemical methods of removing oil stains from the surface of rivers and seas are also used.

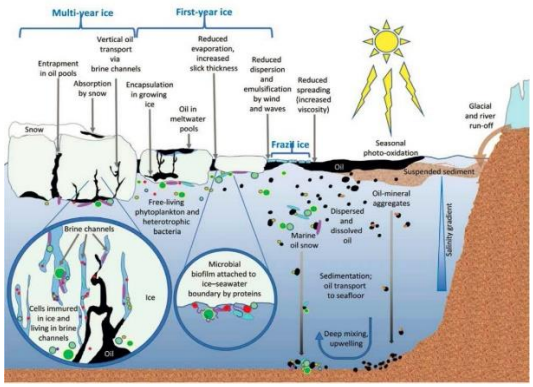

Figure 2 - Overview of the fate of oil in the marine environment.

SOURCE: Image provided courtesy of the American Petroleum Institute, produced by Iron Octopus Productions, Inc.

The developed chemical preparations are absorbents, which are sprayed on pollution in the form of powders or liquids. The expediency of using absorbents lies in the fact that they contribute to the disruption of the oil layer, which blocks the flow of oxygen from the air into the water, pollutes the coast, and kills aquatic animals and birds (Fig. 2)

As a result, exchange processes with the atmosphere and the penetration of sunlight are improved, as well as the decomposition of oil is accelerated.

But decomposition products, some part of oil and the reagent itself remain in the water column or fall to the bottom.

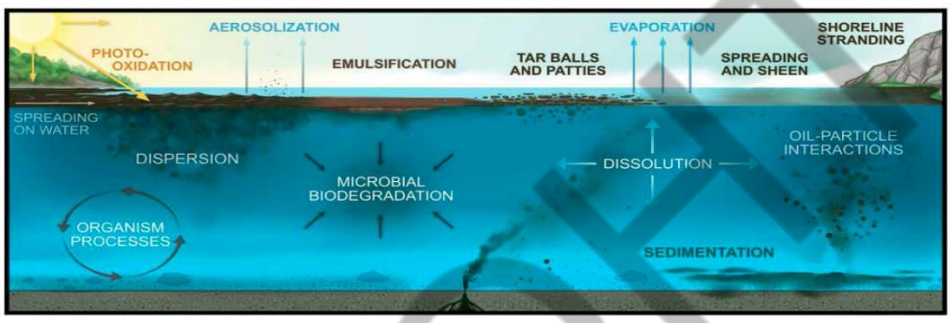

Figure 3 – Chemical methods of removing oil stains from the surface of rivers and seas

The biological method can be noted as a promising, although in many respects, problematic method of neutralization of petroleum products that have entered the water (Fig. 4). It includes the following areas:

- cleaning with the help of plants that assimilate some pollutants contained in water, including hydrocarbons;
- search and research of living creatures capable of capturing and processing water pollutants, primarily hydrocarbons (molluscs, and in particular mussels - for example, dreisen) receive the most attention;

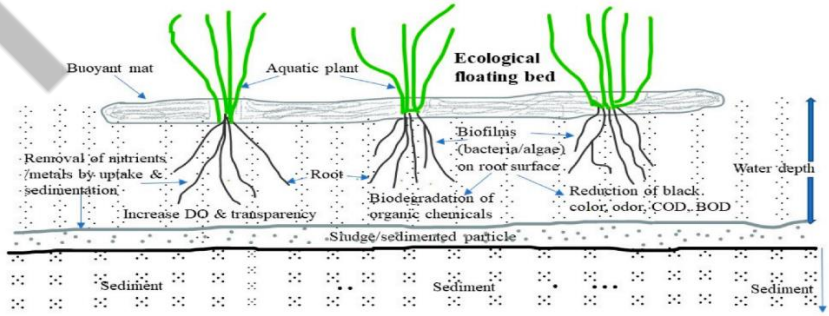

Figure 4 – Biological methods of removing oil stains from the surface of rivers and seas

4 SUBGROUNDS FOR THE IMPLEMENTATION OF GREEN TECHNOLOGIES IN RIVER TRANSPORT

Transportation by inland water transport (hereinafter - IWT) is considered by the Government of Ukraine as a type of transport that must be developed to support the Ukrainian economy by increasing the number of transport and logistics alternatives in order to create a more efficient and sustainable logistics system. VVT has a good potential for reducing logistics costs, fuel costs, air emissions, traffic jams, noise and emergency events.

The Strategy for the Development of Inland Water Transport of Ukraine, developed in accordance with the Law of Ukraine "On Inland Water Transport", is the basis for planning the development of the IWT of Ukraine, for the implementation of the national policy of reforms and the application of the principles of successful governance, including the development of institutional capacity and electronic governance, the fight against corruption and transparency

Effective use of inland waterways of Ukraine (hereinafter referred to as inland waterways) requires solving the following main problems:

– imperfect, outdated, missing and underdeveloped public infrastructure (includinglocks, navigation, general-ship traffic), which does not ensure effective logistics, including the full participation of IVT in multimodal transport chains;

– aging and shortage of modern cargo and technical fleet that would meet European environmental and technical standards;

– imperfect system personnel policy and lack of qualified personnel at the IVT, in particular its aging and lack of social interest among young specialists;

– lack of a clear division of responsibility for the maintenance and development of the VVSh, duplication of functions between the executive power bodies on issues of shipping safety, insufficient interaction between the executive power bodies.

Ukraine has more than 6,000 km of potentially navigable waterways, of which the longest rivers are the Dnipro (1,013 km) and its tributaries - Desna (605.5 km) and Pripyat (62.5 km). The Ukrainian part of the Danube River is 170 km long, the navigable part of the Southern Bug is 199 km long. These three rivers are the main navigable arteries of Ukraine.

Navigation depths on the Dnipro River: from the city of Kherson to the Kyiv HPP – 3.65 meters (with the corresponding depth in the locks), from the Kyiv HPP to the mouth of the Pripyat River – 2.65 meters; on the Southern Bug River - from 1.9 to 2.1 meters (from the city of Mykolaiv to the city of Voznesensk). The width of the waterway on the Dnieper to the mouth of Pripyat is 80 meters. Current repair dredging is carried out to maintain the safe dimensions of the ship's passage.

Freight turnover in 2019 increased by 19.1% compared to 2018. The main types of cargo transported by VVS in 2019 were grain cargo 4.9 million tons (+ 54.3%), metal products 1.7 million tons (+ 32.9%), petroleum products 37.4 thousand tons (-45.9%), building materials and other goods amounted to 5.2 million tons (-4%). The situation with river transportation in 2020, which is a crisis for the economy of Ukraine due to COVID-19, did not change significantly in general, but there were changes in the structure of transportation: 11.23 million tons of cargo were transported, of which 3.53 million tons were grain cargo (- 27.3%), metal products 1.83 million tons (+

6.97%), petroleum products 43.6 thousand tons (+ 16.36%), building materials and other goods amounted to 5.84 million tons (+12.42%)).

The main directions of transportation of VVSh are export and domestic transportation, which account for more than 90% of the total volume of transportation. There is also significant potential in the transportation of mineral fertilizers and containers. A more detailed analysis of the cargo base by directions is complicated by the lack of official statistics on the directions and volumes of transportation (this deficiency can be corrected through modernization and changes in the work of the River Information Service (hereinafter - RIS), in accordance with Directive 2005/44/EC of the European Parliament and the Council of 09/07/2005 on harmonized river information services (RIS) on the inland waterways of the Community.

In fact, obtaining hydrogen consists in the fact (Fig. 2.1) that there are two electrodes in a container with water: a cathode and an anode. They are connected to a power source (for example, to a battery) and an electric current passes through a container of water (electrons start to move). During this, electrochemical reactions take place. With the correct combination of electrodes, electrolytic decomposition of water will occur, the result of which is the release of oxygen and hydrogen

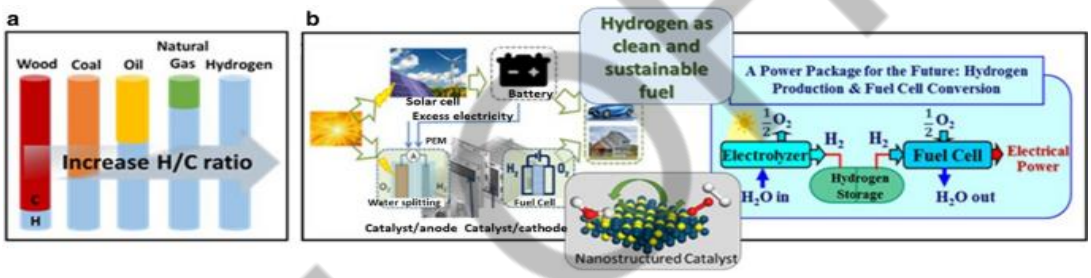

Figure 5 - Hydrogen production by water electrolysis: the role of catalysts

The cathode is a reducing agent: $2H_2O \rightarrow O_2 + 4H^+ + 4e^-$, and the anode is an oxidizing agent: $2H_2O + 2e \rightarrow H_2 + 2OH^-$, respectively, at the cathode, oxygen atoms from water are transformed into gaseous oxygen, and at the anode, hydrogen atoms from water are oxidized to hydrogen gas.

Hydrogen and hydrogen-derived synthetic fuels are projected to account for 2% of total transportation energy demand in 2030, 13% in 2040, and 25% in 2050.

Figure 6 - Hybrid water electrolysis: Replacing oxygen evolution reaction for energy-efficient hydrogen production and beyond

Until green hydrogen achieves commercial appeal, it is envisaged that the development of this sector will be stimulated at European and national levels. The costs

of its production will decrease in the next 10 years, but the questions regarding its transportation and storage still remain the main "puzzle" to be solved. In particular, the development of a network of hydrogen filling stations is necessary for further progress.

Certain steps in this direction are already being taken by the state for the development of the hydrogen transportation and storage system in Ukraine. In particular, the operator of the gas transportation system currently considers the main Ukrainian gas pipeline "Progres" promising for transporting a mixture of hydrogen and natural gas.The Naftogaz and Ukrtransgaz companies, in turn, have already joined the "H2EU+Store" initiative. It envisages the production of green hydrogen from RES in western Ukraine with the possibility of storing it in Ukrainian gas storage facilities. In the future, it is also planned to export this fuel through gas pipelines to the EU, inject it into underground storage facilities in Austria, and sell it to consumers in Central Europe.

In the domestic maritime sector, ships with hydrogen fuel cells are at the stage of demonstration projects. Hydrogen fuel cells can also be used to replace on-board and shore power to reduce polluting emissions and avoid the significant costs of installing electrical connections in the harbor.

In Ukraine, the use of hydrogen in water transport has its own prospects. In particular, over the past 5 years, there has been an increase in the volume of goods transported by river transport, the potential of which has not been used to full capacity (AI "APK-Inform"). The share of transportation of agricultural products by river transport is currently 7%. Decarbonizing the shipping industry will require significant investment in green technologies and alternative fuels. Today, ship owners are encouraged to switch to existing low-carbon fuels such as liquefied natural gas (LNG) and biofuels. However, recent research on green fuels suggests that ammonia, methanol and hydrogen will play an important role in the future of the shipping sector (Figure 3.3).

In the 28 countries of the European Union, inland water transport carries out more than 210,000 million t/km of cargo traffic with a fleet of about 12,000 vessels. At the same time, the center of gravity is undoubtedly concentrated in the area of the Rhine River, which accounts for about 80% of the volume of all transportation.

The total number of inland water transport shipping companies in Europe is 7,662, the turnover of which is EUR 4,222.5 million, and the number of employees in this industry is 30,909 thousand specialists. German shipping companies, in particular Hapag-Loyd, are characterized not only by domestic and cabotage services, but also by liner shipping between all continents. The company includes 150 modern ships (with a total capacity of 770,000 TEU), a container fleet (more than 110,000 TEU) and a refrigerated fleet.

Market. In addition to its traditionally strong position in the bulk cargo market, inland waterway transport has successfully penetrated the Western European markets for transporting high-value containerized goods. However, the advance to the continental cargo market and to the markets in Central and Eastern Europe is just beginning.

New market niches are emerging in areas such as: waste and recycling, dangerous goods, transport of vehicles and extremely large indivisible loads, as well as river-sea shipping.

Personnel. A key element of the personnel strategy is the improvement of the professional and qualification skills of industry specialists. In addition, recruitment initiatives will improve awareness outside the sector of employment and career opportunities in inland shipping. According to European forecasts, inland waterways experience a shortage of qualified labor, in connection with this there is a need to popularize the profession and attract specialists.

Figure 7 – European Green Deal

Reputation. According to the European Economic Commission, the reputation of the inland shipping sector does not correspond to the achieved level of logistical and technological efficiency. That is why it is necessary to raise general awareness and awareness of the real potential of this sector in terms of quality and reliability. Improving the reputation of inland shipping is a joint responsibility of the industry, politicians and administrations at national and European levels. However, the largest amount of investment in the countries of the European Union is received by motor vehicles (17.2 million euros) and air transport (14.7 million euros).

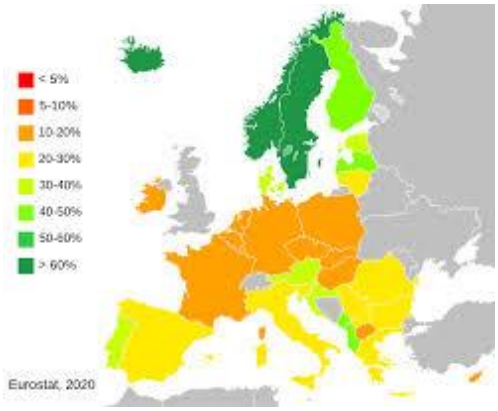

Figure 8 - Renewable energy in the European Union

The third largest railway transport (EUR 12.3 million), sea and river transport occupy the last position, their investment amounts to EUR 7.45 million and EUR 5.3

million, respectively. However, it is worth noting that according to the data presented by the European Economic Commission, the volume of investment in transport, in particular inland water transport, in Europe is insufficient. including water transport.

5.CONCLUSIONS

The paper provides a theoretical justification for the relevance of the implementation of green technologies in river transport. In accordance with the purpose, the following tasks are solved in the paper:

– a scientific analysis of advanced international practice was carried out and the main characteristic features with the possibility of improvement of the internal water transport of Ukraine were determined;

– reasons and sources of pollution by water transport are substantiated;

– the possibility of introducing green technologies in the river transport of Ukraine, the monitoring system of harmful emissions into the environment with the subsequent plan of measures for the implementation of the strategy for the development of inland water transport of Ukraine until 2031 was investigated;

- recommendations were developed to reduce the impact of water transport and negative impact on the environment, modernization and use of hydrogen as a more environmentally friendly type of fuel, taking into account the advanced technologies of the European Green Course.

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PROCESSING OF POLYMERIC AND ORGANIC WASTE USING SOLAR ENERGY AND LIQUID NITROGEN

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Abstract. *With the development of science and technology, the amount of waste isincreasing more and more. And there is still no ecological and materially efficient wayof how to recycle it. To that end, recycling of waste is an acute environmental problem.Purpose of the project – creation of a new efficient method for processing polymeric waste by improving one of the already known. For this processing, we propose to use pyrolysis – thermal destruction at a temperature of 500-600°C. Pyrolysis has two advantages – sorting is not required; we can get fuel from useless waste. But its disadvantages are huge energy outlay and the first stage of combustion. To provide our reaction with the energy we propose to use solar energy as the main source. The needed temperature reaches with the sun activity of 1kW/m^2 while using spherical collector. In addition, we propose to add a Fresnel lens (+ 200°C). Moreover, it makes 'greenhouse effect' in the space between concentrator and camera. So it can keep thetemperature still and make equal heating of waste in all volume of camera. To preventcombustion we need to make the absence of oxygen in pyrolysis camera. For this, we propose to add 100gr of liquid nitrogen for 100L of the camera. The nitrogen expandsin nearly 500 times and ousts air. It becomes the environment of the reaction.Moreover, at that temperatures and pressure nitrogen is an inert gas. In addition, we get higher mass exodus of fuel – pyrolysis gas: 20% to 28%; diesel fuel: 14.25% to 20% – for PET. At the end, by using that technology we can make our process ecological and energy efficient. For that processing, we have received Ukrainian patent #133811. We propose to use our technology directly on the huge landfills, or use 1-2 installations for small city and recycle waste by transporting them from one small landfill to another; all the products of the reaction after additional rectificationcan be used for industrial purposes.*

Keywords: *processing, waste, recycling, pyrolysis.*

I. INTRODUCTION

With the development of science and technology, the amount of waste, which iscontaminating our environment, is increasing more and more. Modern regularly used methods for recycling waste are incineration and mechanical processing (for polymers). But all of them have big disadvantages. The combustion is very dangerous for the environment, a large number of harmful substances are released in the atmosphere. Mechanical processing is very energy-consuming and requires strict sorting. And, for example, polymers that have been laying in the landfills for decades can't be processed by this method.

So there is still no ecological and materially efficient way of how to recycle it.

To that end, recycling of waste is an acute environmental problem.

II. LITERATURE ANALYSIS

2.1. General data on the amount of waste and its processing, environmentalstatus in Ukraine and in the world

Ukraine continues to sink in the rubbish. Every year the amount of waste is increasing – in 2017 Ukraine has accumulated in about 366 million of tons of wastes, which is 70 million tons more compared with 2016.

It is statistically proved that 8,5 tons of waste was added per year to each inhabitant of our country. And all rubbish landfills and dumps in Ukraine contain 12.3 billion of wastes. [7]

According to the State Statistics Committee, the situation with the processing ofindustrial waste remained at the level of 2016: utilized 3% of cars (from 3000 tons), 5% from 40 thousand tons of plastic, 10% from 22 thousand tons of glass, 28% from 23 thousand tons and 50% from 112 thousand tons of paper and cardboard. In 2017, recycling of household waste became better: 257,300 tons (+ 1%) was burned out for electricity and 2,000 tons simply burned down (-5%), utilized 6,500 tones (+ 62.5%) according to European standards. But, according to ecologists, it is only 2.3% of the total amount of household rubbish. And abroad is processed 70% and more of such waste, and in Sweden - 96%, because of which Swedish people for about 10 years buy waste abroad so that their waste processing plants do not stand idle. [4]

At the same time, a large amount of waste is harmful to the environment - such as polymer (they make up about 40% of the total mass). Yes, all well-known transparent drink bottles are made of polychlorinated material – a substance that slowly, but inevitably releases highly toxic, vinyl chloride and bisphenols. These compounds are strong mutagens, which can not only cause prolonged inflammation ofthe mucous membranes, but also lead to oncological diseases. [2]

The plasticizers are added to the composition of many plastics - substances that improve mechanical properties and simplify the technology of manufacturing productsbut also show toxic effects.

And if the use of disposable packaging does not pose a risk, its accumulation insignificant quantities leads to the release of significant amounts of toxic substances. Plastic waste has become an extremely difficult ecological problem, which threatens to grow into a catastrophe not only on land, but also at the sea.

In addition to polymer waste, organic are also "harmful". One of the main sources of dioxins and furans, according to the findings of the "International Best Practices for PreProcessing and Co-Processing of Municipal Solid Waste and Sewage Sludgein the Cement Industry", are the processes of uncontrolled waste incineration. Therefore, with certainty we can say that the problem with waste is very important and relevant.

2.2. Modern waste recycling techniques, comparative analysis anddisadvantages

One of the most problematic and heaviest in waste processing is any kind of

inorganic. So let's focus on it at first.

The main methods of processing polymers are hydrolysis, glycolysis, methanolysis, pyrolysis and mechanical processing. [3]

Mechanical processing is a well-known method that is sufficiently ecological but very energy-consuming. In addition, high-level of sorting is required for the operation of this method. And, for example, rubbish, which has been in the landfill fora long time, is almost impossible to be sorted in this way and it won`t be suitable for mechanical processing.

Hydrolysis (acid hydrolysis) is the splitting of polymeric materials by acid-watersolution at high temperature (in about 200 °C). The main process occurs in a vacuum reactor, which receives a detailed raw material (purified from impurities). The methodof hydrolysis is sufficiently energy intensive, because it requires a large amount of water and is long-lasting. The advantage of the method of hydrolysis is the low sortingrequirements. [5]

Glycolysis is a kind of hydrolysis, its features – the use of glycol in the process of depolymerization and the presence of elevated operating temperatures (up to 300 ° C). Various catalysts are used to reduce the passage time of chemical reactions. The main disadvantage of the given method is the technological features that prevent the use of such raw material for the further production of food plastic.

Methanolysis is a method of splitting polymer waste using methanol. This method belongs to the processes of increased chemical and explosive danger, that`s why it is used in very narrow specialties. In addition, methanol requires very precise preparation of raw materials and is costly from the use of energy resources. [6]

Pyrolysis is a method of thermal destruction in the absence of air. As a result ofthis process, the raw materials are decomposed into monomers. To ensure the passageof pyrolysis, it is not necessary to clean and sort the waste.

When comparing methods according to durability, then pyrolysis takes the first place. At such high temperatures, 99.9% of all harmful substances that have been added to the pure raw material during the creation of the material are destroyed. But at the same time, the given method is the most energy-consuming. [1]

So, by comparing already known methods, we chose pyrolysis. Because it is suitable for any kind of polymers, it does not require sorting. Let`s consider this method in more details and check the possibility of using it for organic waste.

2.3. Pyrolysis of waste

Piro = heat, lysis = destruction. Pyrolysis of plastic is a chemical reaction which consists of the destruction of a large molecule on lower parts at high temperatures in the absence of oxygen (otherwise, there won`t be decomposition but combustion). Pyrolysis is also called thermal decomposition, thermolysis, depolymerization, and others.

At any temperature the molecule fluctuates. The intensity of the oscillations is directly proportional to the temperature. During pyrolysis the molecule is exposed to high temperatures – it starts to oscillate more and more. And because of this the molecule ruptures on little parts.

The products of the reaction of pyrolysis is pyrolysis fuel (diesel fuel - density 0.9 g / cm3), oily substances, pyrolysis gas (hydrodynamic gas - in properties almost completely identical with natural) and atoms of the Carbon Black (Fig. 1.1).

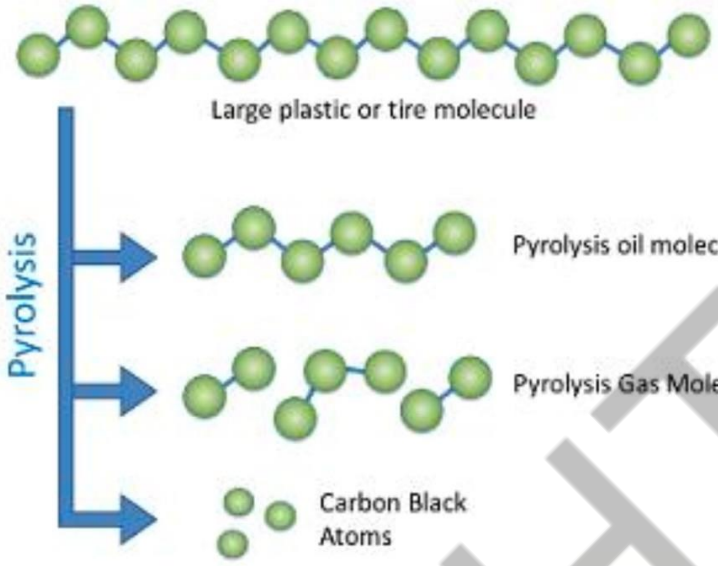

Fig. 2.1. Destruction of the polymer molecule by pyrolysis reaction and reactionproducts.

Next, let`s consider the pyrolysis of organic matters - whether it is possible and what its properties are.

Low-temperature pyrolysis of organic waste occurs at a temperature of 400-500 ° C. That is, at the temperature of the pyrolysis of polymers. So let's dwell on it.

The product of the reaction of this type of pyrolysis is biochar (biocarbonate). Nowadays, the biochar is considered to be the most effective fertilizer. Thanks to the active ions contained in the biochar, carbon does not evaporate into the environment but remains in the soil for a long time, easily absorbed by the roots of plants. Thus, the amount of greenhouse gases in the atmosphere is reduced as well as the threat of the greenhouse effect and global warming. Fertile soils with high yields in the future will provide the solution to the problem of hunger in developing countries, with the subsequent flowering of their economy. The use of ecologically safe means for soil restoration leads to the removal of aggressive chemical products from the soil which affects not only the earth, but also threaten human health.

Other products of the reaction are biofuel and biogas (a mixture of gases - methane, hydrogen, carbon dioxide and carbon monoxide). When heated to the required temperature, the reaction takes place quickly (splitting takes about two seconds).

The main difference between the recycling of biomass and polymers is that they must be dried to produce biofuels in the process of destroying organic wastes. If we leave the water (more than 10% of the total volume) then the final product of the reaction won't be biofuel but the solution to this problem already exists – at atemperature of 150 ° C in a special compartment steam is drawn. (Figure 1.2).

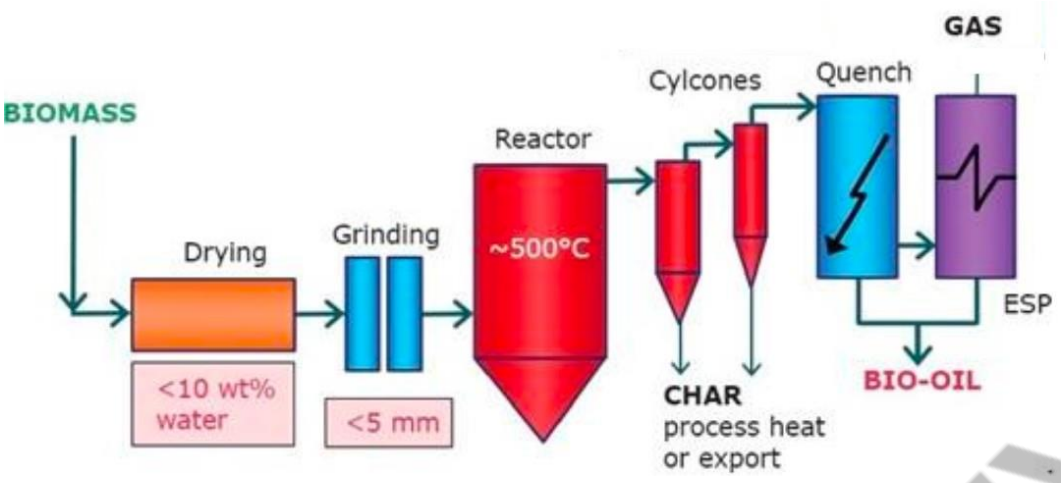

Fig. 2.2. Technological process of pyrolysis of organic waste.

Consequently, the pyrolysis of organic wastes and polymers is possible and occurs at the same temperature (in about 500 ° C), describing the technological process. According to the products of the reaction we have – water, biogas, biofuels and biochar from organic waste (effective fertilizer and organic fuel); pyrolysis gas (natural gas), diesel fuel, oily substances and Carbon Black (raw material for rubber production and manufacturing carbon nano- tubes, fuel for furnaces, boilers).

With the development of science and technology, an increase in the number of people grows the number of waste each year, which poses a threat to our planet and ourselves, contaminating the environment.

Modern widespread methods of recycling and utilization is a mechanical processing and incineration. But incineration is out of question because thus a large number of harmful substances is released. Mechanical recycling (for polymer waste) is very energy-consuming and requires clear sorting conditions. But some types and conditions of plastic, for example, the one that has already started to decompose - most of the modern waste that is in landfills – is not suitable for such processing.

Consequently, the two main problems that arise when considering pyrolysis arehigh energy consumption for raising the temperature and providing an oxygen-free environment.

We propose a possible solution to the first problem – the use of solar energy as the main source. Namely, one of the types of solar collectors (discussed in more detail in subsection 1.4 "Solar collectors").

The second problem is that in modern household installations, oxygen is not removed. And the first step is the combustion of polymers with the release of harmful substances (like dioxins) begins, and only then the pyrolysis itself - we get large losses on the efficiency. In the industry, plastic is first pressed. And then they are placed in the chamber, that is, a small percentage of oxygen that still remains at high energy costs.

To prevent combustion we need to make the absence of oxygen in the pyrolysiscamera. We offer another way to get rid of oxygen: 1) shredding of plastic as it always is done; 2) adding in about 100 grams of liquid nitrogen to 10 liters of plastic, nitrogenwill expand to 600 times and will fully oust oxygen.

It becomes the environment of the reaction. Moreover, at that temperatures and

pressure nitrogen is an inert gas. So it shouldn't take part in the reaction process. And that hypothesis we needed to check by making different kinds of experiments.

2.4. Solar hubs

Let`s consider the common types of solar collectors and their properties – flat, vacuum, parabolic (spherical).

The flat solar concentrator is one of the most fundamental and studied technologies of solar energy. The general idea is simple enough – the sun heats the dark surface that collects the greatest amount of energy. And then the acquired energy is transported to the required substance. The flat solar collectors achieve maximum ofefficiency at a temperature of 30 to 80 ºC. In this case, modern advanced models allowto raise the temperature (maximum is 100 ºC). [8]

Vacuum solar concentrator – works efficiently at temperatures from 77 to 177 °C. The vacuum collector consists of parallel series of glass tubes connected to the main liquid pipe. Each of them is in the outer in order to create a vacuum environment.To minimize the heat loss due to convection and thermal radiation.

Parabolic (spherical) solar collector - made of a plate of reflective or highly polished material, folded in the shape of a parabola. There are two types of such collector - semi-parabolic (semi-spherical) and parabolic dish (parabolic / spherical collector).

The semi-parabolic collector works more efficiently than flat, with a significantly less absorbent surface. It allows the temperature to reach over 300 ºC.

Parabolic plates concentrate solar energy at its focal point – the receiver is located on it. The achieved temperature is from 550 to 650 ºC at an average solar activity. [9]

Thus, the required temperature with moderate solar activity should be achieved using a parabolic (spherical) solar collector. At the same time, there is a slight difference in temperature and with a semiparabolic (hemispherical). Therefore, our goal was to check the speed and the possibility of heating the pyrolysis chamber to the required temperatures when using these types of concentrators. With typical sunny activity in Ukraine.

And also to the experiments we added – checking the application of the Fresnel lens. For greater concentration of rays and equal heating during the industrial process.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

Purpose of the project is the creation of a new effective method for processing polymeric and organic waste by improving one of the already known.

Object of the study – organic and polymeric waste.

Subject of the study – development of the ecological and energy efficient method for processing waste.

Tasks of the project:

1. With the help of laboratory facilities, check the possibility of pyrolysis of adifferent kind of a waste.
2. Create energy independent technology using solar energy (make

experiments with models of spherical and semi-spherical concentrators).

3. Find out the effectiveness of using liquid nitrogen for deoxygenation of pyrolysis camera

For the experiments we have used three models of sun collectors – two models of spherical collectors and one model of semispherical (Fig. 2.1).

Fig. 3.1. Models of sun collectors – spherical (handmade), spherical (stainless steel)and semispherical (handmade) – from left to right.

The spherical was made with metallic framework, paper segments, light-cure tape and superglue. Semiparabolic is cardboard basis, insertions from a foam plastic and the same tape.

The model of pyrolysis stove is a metallic black-pigmented jar (for providing ofabsorption of most of rays).

Additionally the Fresnel lens, by sizes a 210*297 mm, was used. Source of light - one-colour lamp of ZW3 - L500 ("Kanlux"), by power 500 W/0,5 м^2; for a supervision from data of experiment is a multimaster of M838 ("UNI-T") and multimaster OT33C ("UNI-T").

The motion of experiment is heating of the model of pyrolysis chamber by means of a lamp, using the different models of collectors and Fresnel lens - watching temperature rise.

Basic raw material is liquid nitrogen, that at expansion in 600 times will fully oust oxygen. For exactness of experiments hermetically sullenly the pyrolysis chamber, made from stainless steel, was used.

For the increase of chamber temperature a heater stove was used. The gas was taken in a bulb with the help to the pump of HVP (Fig. 2.2).

Experiments with the use of nitrogen was made with polymeric wastes (plastic bottles) and organic (oak leaves that were preliminary dried out). Before this necessary raw material was grinded.

Fig. 3.2. Setting of experiment and addition of liquid nitrogen.

Motion of experiment is heating of pyrolysis chamber (by means of stove) and taking of gases by 2 pumps of HVP.

As, we worked with high temperatures, then one of basic equipments was a fire-extinguisher in a laboratory.

And also a face-guard (during work with liquid nitrogen) and sun-blinkers (at heating of solar collector with the lamp) were used.

IV. RESULTS

4.1. Heating by means of collector

We did 6 experiments - each layout of concentrator separately and their combinations with Fresnel lens (fig. 3.1).

Fig. 4.1. Watching the temperature change and method of fixing of Fresnel lens.

Thus, the results of heating at lamp power in 500 W/0,5 m^2 are given in Table 3.1.

Table 3.1 Temperature indexes at heating spherical, polished spherical and semispherical collectors

Applied model	**At heating with a lamp, ^{o}C**	**At power in 1 kW/m^2, ^{o}C**
Polished spherical	178	712
Spherical	145	580
Semispherical	67	268

Temperatures at power in 1 kW/m^2 are expected in theory (obviously, they are greater exactly in 4 times compared to temperatures at 500 W/0,5 m^2). Middle amount of sun radiation of Ukraine (according to certain regions in kW/m^2): Volyn – 0,98; Zakarpattia – 1,16; Khmelnitsk –1,03 Donetsk – 1,18 Chernihiv – 1,08 Kherson – 1,28; Sumy – 1,11; Odesa – 1,29; Kyiv – 1,11; Poltava – 1,14. And mostly all countries starting with temperate climate to equatorial has that or higher average sun activity. That, the temperature which will be gained in the sun is suitable for pyrolysis. Therefore we choose it for creation technology.

At addition of Fresnel lens on unit of power (1 kW/m^2) we will get step temperature in 200 ^{o}C. As, in summer in daylight there are also clouds which can close the sun for some time, we offer to place Fresnel lens on the collector surface. So we can provide more even heating, as, the concentration of rays will take place not only on the lateral walls of pyrolysis chamber. But due to a hotbed effect, at the temporal closing of the sunthe temperature will not instantly fall down.

4.2. Research of ECE of setting at the deoxygenation of environment by liquid nitrogen

We made 4 experiments – with organic and inorganic wastes in combination with nitrogen and in an oxygen environment (nearly a third of air).

On 10 litres of waste we add approximately 100 grams of liquid nitrogen which at a hit in a pyrolysis chamber will expand approximately in 600 times. It will oust oxygen completely. In further reaction (at the temperatures and pressure of pyrolysis) it will be inert gas.

In experiments with polymeric wastes we got such data: 14,25 % - fuel-oil; 50,5% - Carbon Black; 20% - natural gas; 12,7 % water and harmful matters (carcinogens) which were selected as a result of the initial stage of burning. At addition of liquid nitrogen we got an anoxic environment. We got: about 20 % - fuel-oil; 31% - Carbon Black; 23 % - natural gas; 16 % water.

There is the same tendency with organic waste. Shortchanging carried out not with the got raw material, but in theory. After an output approximate relations got only between the amounts of gaseous, hard and liquid matters.

Thus, at the deoxygenation of environment, we are fully delivered from the origin of harmful substances, so we do the process maximally ecological. And we increase the percentage of useful substances (that and ECE) – such as fuels (diesel andbiopropellants).

4.3. Generalization of the results

After the made experiments, we formed the reference chart of the effective setting (Fig. 4.1).

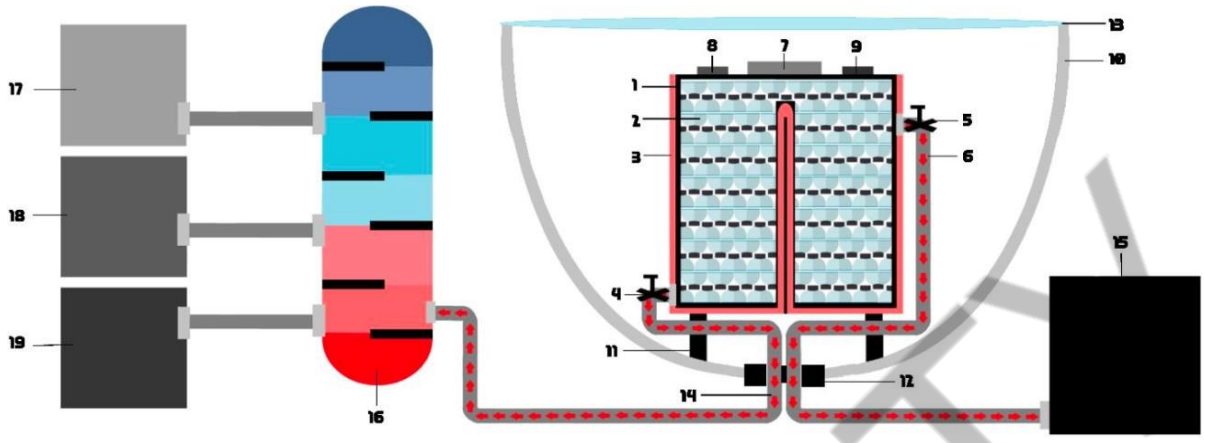

Fig. 4.1. Developed technology: 1 - a pyrolysis chamber; 2 - wastes; 3 - a copper plating; 4 and 5 - valves; 6 and 14 - flexible pipes; 7 - a lid; 8 - a sensor of temperature; 9 - a pressure transducer; 10 - a spherical sun concentrator; 11 - bases;12 - the air-tight fixing; 13 - Fresnel lens; 15 - a container for collection of gas; 16 -fractionating column ; 17 - a container for water; 18 - a container for a fuel; 19 - a container for an oily matter.

Consequently, we use a spherical collector for raising the necessary high temperature – pyrolysis is energy independent and passes only by means of solar energy.

The Fresnel lens will provide the greater concentration of sunrays and will allow a temperature to be maintained at temporal absence of receipt of sun energy (due to thegreenhouse effect).

Also, a lens and a copper plating are necessary for the equal heating in whole volume ofpyrolysis csmera and smooth passing of reaction.

Preparation of raw material for a process: waste passes through mechanical screw which also works on sun energy; then we add liquid nitrogen. Thus, we can solve a problem with the deoxygenation of environment and do the method of pyrolysis completely ecological.

So we solve the problem with the initial stage, which is burning, that is peculiar to many settings. Furthermore, pressing is used on industry. At the same time plenty ofenergy is spent (the value of which is far greater the value of necessary amount of nitrogen) and however there is a little percent of oxygen left. Therefore the offered method of deoxygenation is a large improvement to technologies existing nowadays. The patent application on invention was filled.

Also the important feature of our technology is transportability. It can be transported from one dump to another. And we can gradually process wastes at a time. It is especially currently for small trash accumulations in the forests and villages.

4.4. Economic value of the project

Raw material for diesel fuel is available in the world, and it is possible to organize the energy and fuel production from the polymer garbage in these areas. To

recycle biomass in a reactor by pyrolysis it is necessary to create a temperature regime of about 550 °C.

The rate of thermal energy for the decomposition of organic waste and the creation of the necessary thermal regime in the reactor can be assessed by the formula 1:

$Q_{rec} = c_p \cdot m_p \cdot (t_1 – t_2)$ кJ, де ()c_p - thermal capacitance of polymer waste, kJ / (kg · K);m_p - plastic mass, kg;

t_1 - initial temperature of polymer (before processing), °C;

t_2 –final temperature of polymer (pyrolysis temperature), °C;

We could use as a polymer waste PET (polyethylene terephthalate) - the raw material from which plastic bottles are made, it is one of the most commonly used. The rate of thermal energy for waste recycling using the following data is the following:

c_p = 1 kJ /(kg·K); m_p =100 kg; t_1 = 20 °C; t_2 = 550 °CQ_{rec} = 1 · 100 · (550 – 20) = 53000 kJ

$$Q_{rec} = 1 \cdot 100 \cdot (550 – 20) = 53000 \text{ kJ}$$

The thermal balance of the camera has the form (formula 2):

$$Q = Q_{rec} + Q_{loss} – Q_c \quad (2)$$

Q – total energy rate, kJ;

Q_{rec} – energy rate for recycling, kJ;

Q_{loss} – losses of thermal energy by biomass recycling in the reactor, kJ;Q_c – amount of solar energy needed for recycling, kJ.

We could make the equation of the material balance (formula 3):

$G_w = Gbc + Gdf + Gng$ kg, where (3)G_w – mass of waste, kg;

G_{bc} – mass of the Carbon Black which is obtained during the processing, kg;G_{df} – the amount of diesel fuel that is obtained during the processing, kg; G_{ng} – quantity of natural gas received during processing, kg.

The amount of solar energy that is used for processing will fully provide the process that was proved by experiments.

We represent the calculation of the economic efficiency of this unit, at diameter of the collector - 2,5 m; volume of a pyrolysis camera in 100 litters.

While processing 1000 kg (on average 10 cycles per 100 kg) of polymers per day:

a) Carbon Black: 1000 kg · 0.31 (mass content) = 310 kg / day;

b) diesel fuel: 1000 kg · 0,2 = 200 kg / day;

c) natural gas: 1000 kg · 0.23 = 230 kg / day.

During a year (for a period of sufficient sunny activities - 95 days) it will be received:

a) 310 kg/day · 100 days = 31 tons of Carbon Black;

b) 200 kg/day · 100 days = 20 tons of diesel fuel (density 900 kg/m^3 – 22,2 m^3);

c) 230kg/day·100 days = 23 tons of natural gas at a gas density of 0.7 kg/m^3 (thus 32,800 m3 of pyrolysis gas)

The cost of the received products – 4 280 USD (Carbon Black - 138 USD/ton); 9 000 USD (diesel fuel); 6 560 USD (pyrolysis gas – 0,2 USD/m^3). In total: 19 800 USD.

In order to determine the economic efficiency of the pyrolysis unit it would be necessary to take into account the costs of its producing (16 500 USD), installation and operating costs (costs of raw materials, salaries for staff, nitrogen consumption). In total annual expenses could be calculated at about 10 150 USD. Then the net income per year would be 9 650 USD. Thus, the invested money could be pay off for 2 periods of solar activities of 1 kW/m^2 - 2 years (16 500 USD / 9 650 USD = 1,7 period).

Conducting the similar calculations for the recycling of polymer waste, we have approximately the same result. Our investments will pay off for the same 2 years.

V. CONCLUSIONS

1. We have improved the method of pyrolysis recycling.
2. We have conducted the experiments with heating using various types of solar collectors in order to create a non-volatile device.
3. We have made the energy efficient and energy independent technology of processing polymeric and organic waste in one camera at the same time.
4. The created unit is mobile and can be widely used and easily transport into a necessary place that will allow the plastic to be recycled gradually in any landfill.
5. We have created a new method of making the absence of oxygen in the pyrolysiscamera, which can help us to save energy, sources and make the process fully ecological - for that technology we have applied for a patent.

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DETERMINATION OF SOIL RADIOACTIVITY AND ITS IMPACT ON THE HUMAN BODY

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Annotation. *The contaminated soil exported for burial can be classified as low radioactive waste.*

For recultivation and restoration of the natural background of the content of radionuclides in the soil cover the methods using specially selected perennial plants, which in due course neutralize sources of ionizing radiations to the natural background are offered.

Calculated-experimental estimation of method's quality indicators (correctness and accuracy) using a set of samples for estimation in the form of certified mixtures of aqueous uranium solutions was carried out.

Key words. *soil radioactivity, impact, human organism, contaminated soil, remediation, recovery, natural background.*

INTRODUCTION

Topicality of the work. On uranium mining and processing enterprises during extraction, transportation and processing of ore-containing solutions and also during auxiliary works, release and dispersal of radioactive and harmful chemical substances posing danger to the personnel, population and environment takes place, in connection with this definition of actions at planning deposit liquidation which will provide return of the object of subsoil use, studying of influence of radiation on a human body possess considerable urgency

Purpose of work:

1. analysis of existing recommendations to determine the radioactivity of soils

2.Choice of optimal methods for determination of impact of radioactivity on human organism

Research objectives:

1. Determination of radioactivity of contaminated soil under the day surface;

2. to determine the impact of radioactivity on the human organism.

Research methods: Measurement and analysis of radioactivity of contaminated soil under the daytime surface, study of impact of uranium on human organism.

Subjects of the study: Production activities of Kharasan-2 facilities; baseline data on the environmental condition of the mine site, contaminated soil, study on the impact of uranium on the human organism.

Subject matter: Soils contaminated with uranium under the day surface, human organism.

Novelty of the research: recommendations for determination of radioactivity of soil and estimation of influence of radioactivity on organism of human organism are given.

Theoretical and practical significance of the work: The theoretical significance of collected data will be used for comparative analysis with new data obtained in environmental studies, with the help of described method operational control and operational procedures predetermine increased attention and responsibility for safety requirements of personnel. The practical significance of the work is that the data will allow to determine the risks of negative impact on the environment.

SECTION 1. RECOMMENDATIONS FOR DETERMINING THE RADIOACTIVITY OF SOILS

1.1 Radioactivity of uranium

At present, uranium mining by the in-situ leaching method is the raw material basis for the existence of the uranium industry in the Republic of Kazakhstan. Uranium reserves in deposits suitable for development using this method are extremely large and can ensure highly profitable production for many years.

Sulphuric acid is used as a leaching agent. However, the high kinetics of sulphuric acid interacting with feldspars and carbonate minerals in ore-bearing rocks under complex mining and geological conditions impedes the leaching process and requires a repair and recovery operation (RRA) at the well site. Conducting RWR involves dismantling submersible pumping units followed by decolmatisation of the well, which is risky and may lead to environmental safety violations at the enterprise. Also, when collimating the productive horizon, current lines change direction, which may lead to unplanned spreading of technological solutions, as a result of which a part of leaching solution will flow into nearby aquifers, which will lead to their contamination.[2]

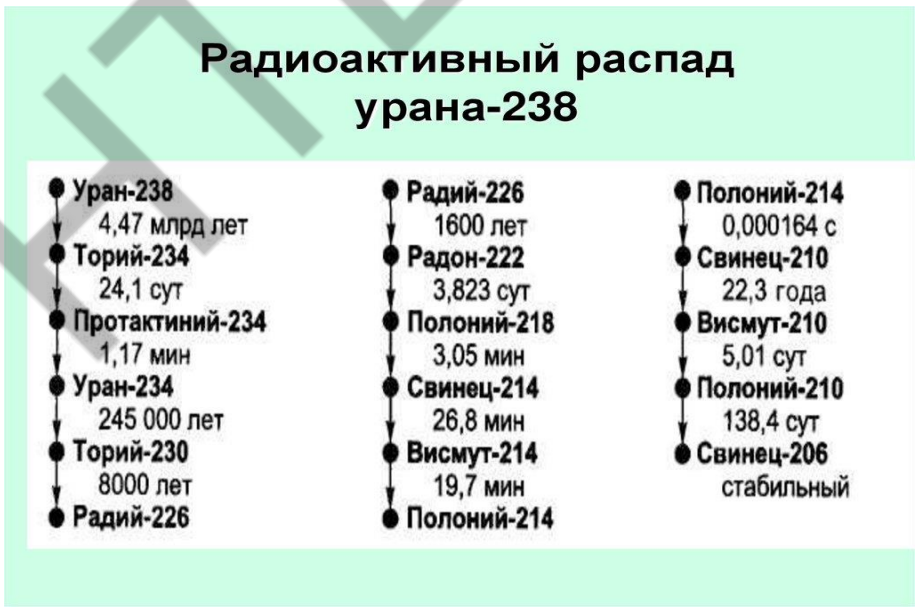

Figure 1 Radioactive decay of uranium -238

1.2 Requirements for reclamation of waste sites

Thus, in the process of downhole uranium mining there is a negative impact not only on the formation water of the producing horizon but also on the surface soil layer of ions of heavy and radioactive metals, sulfate, silicon, aluminum, and precipitated components of the host rocks. These contaminants are detrimental to human health as well as flora and fauna after the extraction process is completed, making the soil unsuitable for further use.

Currently, the main requirements for remediation of waste sites are removal and decontamination of soil containing harmful components and compounds, elimination of residual acidity of groundwater of the productive horizon and reduction of uranium content in solutions to minimum values. However, unified requirements for remediation of formation waters and regulatory documents strictly regulating the residual content of heavy metal salts in formation waters have not yet been adopted due to the complexity of the issue that requires multilateral consideration and study.

The technology of reclamation of sites after borehole uranium mining involves dosimetric and radiometric measurements of the geotechnological field with removal of soil in places where radiation limits are exceeded, followed by its replacement with a previously collected fertile layer that has no chemical or radioactive contamination. The contaminated soil is classified as solid radioactive/low-level radioactive waste (SRW/LLRW) and is to be disposed of in specially equipped burial sites, tailings ponds [1]. In case of large volumes of SRW, these methods require significant capital investment due to labour-intensive processes associated with the removal, handling and storage of large masses of contaminated soil.

SECTION 2. RESULTS AND RECOMMENDATIONS FOR DETERMINING THE RADIOACTIVITY OF CONTAMINATED SOIL

2.1 Assessment of the volume of contaminated soil

In order to estimate the volume of contaminated soil under the day surface, measurements of alpha-activity of selected samples in the soil layers and the minimum effective dose (MED) on the day surface were made. Based on the results of measurements, the graph of dependence of total alpha-activity in soil samples on the DER on the day surface was plotted in the figure. The graph shows vertical dashed lines for layers from 25 to 100 cm, when exceeding 1200 Bq/kg occurs. It can be concluded from figure 1 that alpha-emitting radionuclides penetrate the 25-50 cm layer at a DER on the daytime surface of the earth of 0.7 μSv/hour, the 50-75 cm layer at 1.2 μSv/hour and the 75-100 cm layer at 2 μSv/hour.

Thus, laboratory analyses show that alpha-emitting radionuclides are located both on the soil surface and penetrate deep into the soil, with their spreading depth reaching 1 m in some places. Average contamination by layers is: 1812 Bq/kg (for 0-25 cm layer); 3548 Bq/kg (for 25-50 cm layer); 3305 Bq/kg (for 50-75 cm layer); 1811 Bq/kg (for 75-100 cm layer). Although the minimum specific activity of Ra-226 is 10,000 Bq/kg, the contaminated soil can be classified as low-radioactive waste.

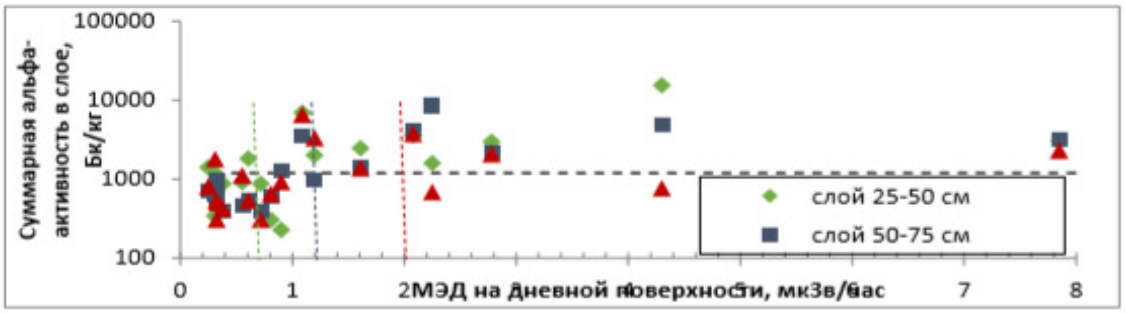

Fig. 2 Dependence of total alpha-activity in soil samples on the DER on the day surface

2.2 Degree of soil contamination

Any soil may be considered as a heterogeneous, multiphase system consisting of three phases: solid, liquid and gaseous. Mineral formations dominate in the solid phase (50... Minerals in solid phase are predominant (5060% of total content of soil): primary (quartz, feldspars) and secondary (clay minerals: kaolinite, montmorillonite, hydromica, mixed bed minerals; minerals of iron, aluminium, manganese and silicon oxides; salt minerals: dolomite, soda, calcium, magnesite, trona, gypsum, anhydrite, mirabilite, halite, phosphate, nitrate, sulphide and other).) minerals. This phase also includes various organic matter (up to 10%), including humus or humus humus and soil colloids of organic, mineral or organomineral origin.

Liquid phase of the soil (solution of the soil, 25...30 %) is water with dissolved in it organic and mineral compounds and gases.

Gas phase of the soil (15.25 %) is the "soil air" including gases that fill up the pores free from water and also gases adsorbed by colloid particles and dissolved in the soil solution.

Contaminated land to be remediated according to the "Sanitary and Epidemiological Requirements for Radiation Hazardous Facilities" must comply with radiation safety requirements [11].

SECTION 3. STUDY OF HUMAN EXPOSURE TO RADIOACTIVITY

3.1 Results and Recommendations for Investigating the Effects of Uranium on the Human Body

In the course of work the aim was to develop a simple and effective methodology using direct ICP measurement in a sample that allows quick and accurate measurement of uranium in human urine for use in the service laboratories of NAC Kazatomprom JSC.

To date, there are radiation safety rules and standards in the Republic of Kazakhstan, which all services at production enterprises adhere to. At the same time, mandatory medical examinations of employees are conducted.

As is known, natural uranium consists of three uranium isotopes: 234U, 235U, and 238U. While the activity of each uranium isotope is known, there is little information about the degree of long-term adverse effect on human organism (tissues,

organs) and there is no evidence to suggest any diseases caused by contact with uranium technological products (technological solutions, gases).

The harmful effects of uranium are due to its combined radiation activity and chemical toxicity. Initially the chemical toxicity of uranium predominates in case of early exposure. The kidneys are primarily affected. In the body, uranium is mainly bound into carbonate/bicarbonate complexes such as [UO2(CO3)2]2-. These complexes are stable at neutral pH (in blood) and are not highly reactive. However, at low pH (in urine) a highly reactive uranyl ion [UO2]2+ is released. Increased uranium levels in the body lead to decreased glomerular filtration in the kidneys, tubular secretion of organic anions, and reabsorption of glucose and amino acids in the proximal tubules [3].

The most effective method for solving this problem according to the combination of such indicators as expressiveness, accuracy, detection limit, selectivity is the method of mass spectrometry with inductively coupled plasma (ICP-MCP) [4]. For ICP-MS measurements of uranium isotopes in urine, a standard test method is available [5], which requires specific sample preparation (ion exchange separation of uranium from the sample matrix) and expensive isotope standard samples produced abroad.

Instruments and methods. A quadrupole mass spectrometer with inductively coupled plasma NexION 350X manufactured by Perkin Elmer was used for method development (Figure 2). Experimental work on selection of optimal instrumental parameters of mass spectrometer was carried out. The selection criteria were maximum sensitivity and rapidity of measurements, minimal influence of sample biomatrix. Tuning of the mass spectrometer (parameter optimisation) is carried out using the isotope uranium-238. For obtaining ultrapure water the Arium 611 UF Sartorius AG' system was used to obtain water with a resistivity of 18 MΩ/cm2. The VITLAB Micropipette single channel pipette dispensers with a dosing range of 10 - 100 mm3' 100 - 1000 mm3, 0.5 - 5 cm3 and 1 - 10 cm3' providing an overall dosing error not greater than 1.5 % were used for the preparation of solutions

Fig. 3 General view of the ICP NexION 350X

Reagents. Nitric acid concentrated o.s.p. (Merck, Germany) and CGU1 Inorganic Ventures CO uranium sample with a nominal (whole number) certified value of 1001 µg/cm3.

Samples to be analysed. Open acid thermal decomposition was used for the analysis of urine samples and for the metrological characteristics of the MBI.

Conducting the measurements.

A nitric acid solution similar to the analysed samples was used as a blank.

Recommendations [6,7] were taken into account for the choice of sampling conditions, urine sample storage and sample preparation.

Human urine has a complex composition and significant matrix variability. Typically in ICP MS for the heavy mass region the matrix influence consists of a significant underestimation of the analytical signal. In order to reduce the influence of the matrix on the analysis it must be destroyed or separated from the component to be determined or corrected by some method or other. In the present work, an internal standardisation method widely used in spectrometric practice was used to correct the matrix underestimation of the analytical signal of uranium (the sum of isotopes uranium-235 and uranium-238). In mass spectrometry, an isotope of an element that undergoes a matrix effect similar to that of the element being determined and that is absent in the objects of analysis is selected for this purpose. In this work, thorium-232 (monoisotope) is also chosen as the optimal internal standard for the measurement of uranium because of the closeness of the atomic mass of thorium and the value of the 1st ionisation potential to the same characteristics of uranium. The internal standard is introduced into the diluted sample to be measured and into the diluent solution (in this case 5% nitric acid).

Figure 3 shows the functional diagram of an MBI uranium content in urine samples using the internal standard method for thorium-232.

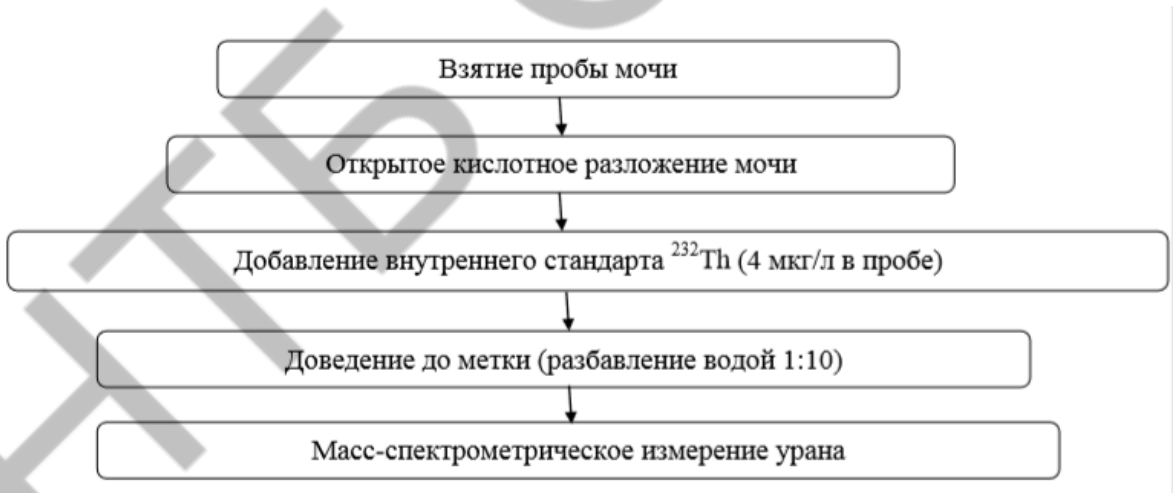

Figure 4 Functional diagram of the MBI

Figure 4 shows the experimental dependence of the matrix coefficient k for uranium on the dilution rate of urine. The value of the matrix coefficient k is calculated using the formula (in r.u.):

$$k=Is/Ix$$

where: Is - measured intensity of uranium ion signal in diluent solution (5% nitric acid), imp./s;

Ix - measured intensity of uranium ion signal in diluted urine solution, imp./s.

From the data in Figure 2, a rough estimate of the multiplicative factor to account for the systematic component of uranium measurement error is ~1.04 (ratio of a for uranium and thorium), this factor should be entered into the calculation of uranium measurement results as a multiplicative correction.

Figure 4 shows the linear change in the matrix coefficient as a function of sample dilution and the presence of a multiplicative systematic error in uranium measurements with internal standardisation of thorium-232, characterised by different coefficients - a in a linear function of the form

$$y=ax+1 \quad (1)$$

where: y is the value of the matrix coefficient calculated by formula (1), r.u;

x - the dilution factor of the urine sample, in relative units.

To calibrate mass-spectrometer we used Inorganic Ventures (USA) standard sample (MS) of uranium composition with relative error of the certified value of uranium content not more than 1 % (P=0,95). Mass-spectrometer software automatically approximates and performs construction of linear calibration characteristic in coordinates: value of signal intensity (in imp./s) - value of mass concentration of uranium (in μg/dm3). Calculation of uncorrected mass concentration of uranium is carried out by software automatically in the method of quantitative analysis (Quantitative Analysis) according to the input data (dilution factor).

In accordance with the recommendations [8] calculated and experimental evaluation of method quality indicators (precision, accuracy and precision) was performed using a set of samples for evaluation in the form of certified mixtures (AC) of aqueous uranium solutions. The mixtures are solutions with certified uranium content values according to [9], and

are prepared by diluting the CRM of uranium with a solution based on natural human urine corresponding to the composition of average daily human urine.

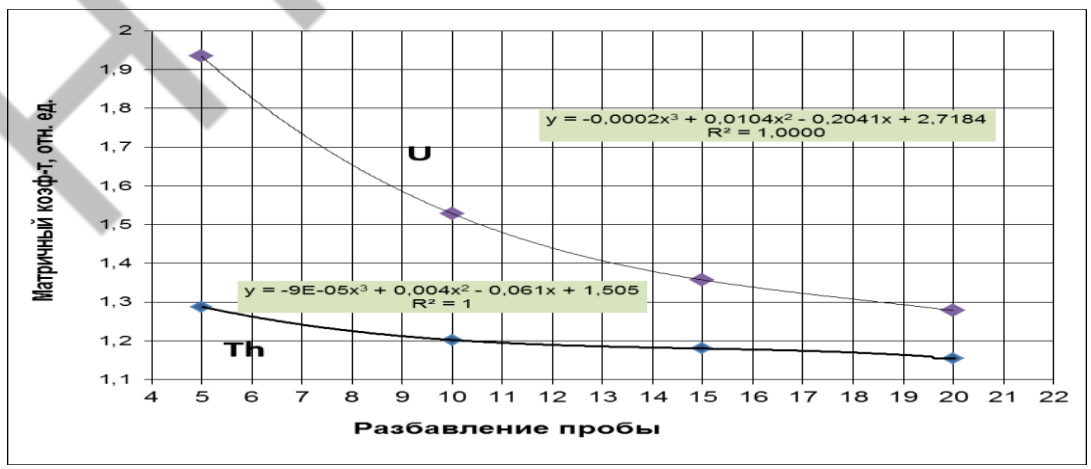

Fig.5 Dependence of the matrix coefficient for uranium and thorium-232 on the degree of dilution of urine

Experimental works on set of statistical data (results of measurements of uranium content in evaluation samples obtained under regulated conditions) for evaluation of quality indicators were performed. As a result of statistical processing of the evaluation experiment data the quality parameters of the technique [8] (repeatability, reproducibility, correctness and accuracy) were determined.

For the lower limit of uranium content which was found experimentally-calculated with regard to recommendations [10] the assigned error characteristics (at P=0.95) of MVI were as follows

- value of repeatability index not more than 0.15 r.u;
- value of accuracy index (error margin) not more than 0.6 c.u.

3.2 Reference value standards

Standards and response actions

The monitoring of uranium in human urine of uranium mine workers is an important component of the dosimetric control system for occupational internal exposure of personnel exposed to open radionuclide sources based on natural uranium. In order to determine who must be monitored for internal exposure, it is necessary to analyse how and to what extent the employee comes into contact with products of uranium processing in uranium mining facilities. Conventionally, all monitored personnel can be divided into several risk groups:

-I group: personnel permanently working with uranium processing products at the process solution processing section, personnel working in the refining shop, FHL personnel, personnel working in the geotechnical field with uranium rock, cores and sludge.

-Group II: personnel working in the uranium mining enterprise who periodically come into contact with technological products of uranium processing, engineering and technical personnel, employees of the administrative and economic complex on the territory of the uranium mining enterprise.

In order to determine which norms of reference values will be relevant to employees of the uranium mining industry in Kazakhstan, it is necessary to study the experience and experience of leading companies and countries in this industry.

According to US Nuclear Regulatory Commission recommendations [11], urine testing is required for workers 1) who are constantly or periodically exposed to airborne forms of uranium compounds or who are directly involved in maintenance work in areas where airborne exposure to uranium compounds is likely, or 2) who are daily exposed to uranium ore dust. Urine testing is recommended for each worker before the first assignment to a designated job. Bio-tests shall be carried out if there is any reason to suspect inhalation dose in excess of the exposure to an average concentration of uranium concentrate of 3.7·10-6 Bq/ml for a 40-hour work week or an average ore dust concentration of 3.7·10-6 Bq/ml (based on total air volume alpha activity) for one quarter; if respiratory protection is used to reduce inhalation doses below specified limits, urine testing shall be performed to check the effectiveness of personal and/or collective respiratory protection equipment

Workers in production areas with uranium compounds may be exposed to dose loads due to variable levels of uranium-containing particles in the air, which may cause chemical damage to the kidneys. Urine uranium analysis should therefore be performed at sufficient intervals to detect such internal doses before uranium is removed from the body.

Samples for urine uranium analysis are taken at least 36 hours after the donor has been at the production site. This delay is necessary to remove the portion of the uranium that is excreted bypassing the kidney tissue. Since this method of monitoring internal exposure is of value when implemented in the plant in a monitoring mode with feedback for prompt intervention and corrective action, the frequency of testing for Group A rotational workers becomes a key factor. Thus, according to [12], the frequency of urine sampling depends on the estimate of the amount of incoming uranium and the solubility of inhaled material, but cannot be less than once a month. It should be noted that the effectiveness and informativeness of the method decreases dramatically if the urine uranium content is measured not in the monitoring mode, but, for example, once a year - during the annual occupational examination for Group A personnel.

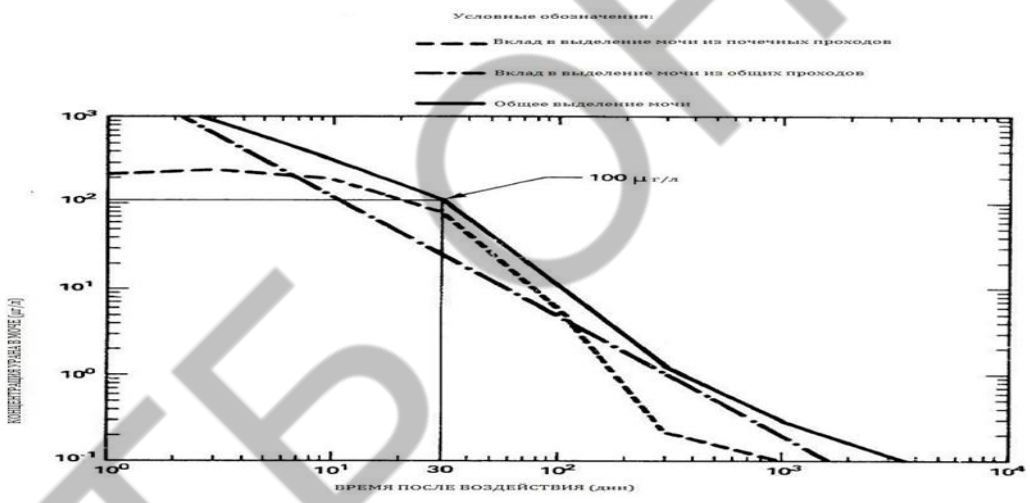

Figure 6 - Urine uranium content after one exposure to low roast uranium concentrate (intake = 260000 μg uranium, equal to 1 annual intake limit), from NUREG-0874.

Decision making within the production dosimetry system, possible corrective actions/measures depend on the identified levels of uranium in the urine of the donor. It is accepted that when the urine uranium content is less than 15 μg/l (study level), surveillance (monitoring) continues without special action [12]. However, it should be kept in mind that any confirmed positive urine test results are an indication of the presence of soluble uranium affecting the kidneys.

Thus, if a concentration between 15 μg/l and 35 μg/l is detected, the following actions are prescribed by the guidelines:

1.Carry out a repeat analysis to confirm the results.

2.Determine the cause of the elevated levels and implement additional control measures if the result is confirmed.

3.Review air sample data to determine source of exposure and dose levels.

4.Determine if other workers may have been similarly exposed and measure bio-samples for them.

5.Set work restrictions until uranium content in donor urine is below 15 μg/l.

If concentrations above 35 μg/l (immediate action level) are detected, dosimetric measures to protect against uranium and probably air sampling programmes are not acceptable. In such a case, the following actions are prescribed:

1.The operation of the production area can only be continued if there is actual certainty that other workers do not have uranium concentrations in urine of more than 35μg/l.

2. Limit admission to work for contaminated workers or increase protection measures against uranium if the cause is ore dust or uranium concentrate with a high calcination temperature.

3.Analyse bio-samples weekly.

For the whole period of research, no values higher than 4 μg/l were detected in urine bioassays (urine samples from more than 40 different donors were used in the development).

The operational control and surgical procedures introduced by the method described above predetermine the increased attention and responsibility for the safety requirements of the staff, the use of PPE, and serve as an additional check on the reliability of the safety of the technological process.

CONCLUSIONS

Recommendations on the use of specific methods to determine the radioactivity of soils have been put forward. For reclamation and restoration of natural background of radionuclide content in soil cover the methods using specially selected perennial plants which in due course neutralize sources of ionizing radiation to natural natural background have been offered.

Methods to assess the impact of radioactivity on human organism were analyzed and optimal ones were selected. Calculated-experimental estimation of method quality indicators (correctness and accuracy) using a set of samples for estimation in the form of certified mixtures of aqueous uranium solutions was carried out.

The contaminated soil removed for disposal can be classified as low-radioactive waste, although its activity does not exceed the minimum significant specific activity. To solve the issues of reclamation and restoration of the natural background of radionuclide contents in the soil cover over large areas it is necessary to develop new methods of reclamation using specially selected perennial plants that with time neutralize ionizing sources of ionizing radiation to the natural natural background.

Sanitary condition of soil is assessed by a number of hygienic indicators, among them: sanitary number (ratio of protein nitrogen to total organic content); presence of E. coli (coli-titer); fly larvae, helminth eggs. According to the set of these indicators the soil is assessed as clean or contaminated.

There are a number of additional indicators of the sanitary state of the soil, determined in the territory of industrial enterprises and settlements:

- Sanitary-physical-chemical assessments that relate mainly to soil leachates (sanitary number, acidity, biochemical p

- Sanitary helminthological assessments characterizing the presence of helminths (worms parasitizing in human, animal and plant organs, etc.) in soil in areas frequented by the public

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POST-MINING AGRICULTURE ON WASTE OF MINERAL ORIGIN

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Abstract. *The object of research is the process of handling mining waste and the produced mining space of closed mines. According to the Energy Strategy until 2035, it was planned that measures to close or conserve unprofitable mines should be completed by 2025. The issue of mitigating economic, ecological and social consequences will become particularly relevant, which, in particular, can be solved through projects of effective use of the produced mine space and mining waste. Modern approaches to the disposal of mining waste and methods of using the produced space of closed mines are analyzed. It has been established that such waste is mainly used in the construction industry, and the volumes of use are insufficient to neutralize the impact of dumps or slagheap on the environment. The chemical composition of mining waste, in particular quartzite screening, was analyzed, and an experiment was conducted to determine the possibility of growing crops using a hydroponic system using a special solution of filtered water with the addition of rock in a ratio of 100 ml:100 g. An experimental study was also conducted to determine the possibility of attracting produced mining space of closed mines for growing agricultural crops in it. For the experiment, they chose a universal experimental culture - watercress. The results of the experiments showed that growing watercress using a hydroponic system with the addition of a solution (filtered water with the addition of rock in the ratio of 100 ml: 100 g) under normal conditions and in the dark stimulates an increase in the root system by 45%. A more developed root system allows the culture to receive more moisture and nutrients, thereby increasing its endurance and drought resistance. The obtained results can be explained by the positive influence of silica, which is more than 90% in the composition of rock, on the growth and development of crops. It is proposed to increase the level of environmental safety of mining regions due to the use of mining waste as fertilizers for agricultural crops, as well as the produced mining space of closed mines for their cultivation. This approach will reduce the ecological footprint of the process of growing agricultural crops, in particular due to the reduction of the use of fertile arable land and, accordingly, of traditional fertilizers, which are the source of such a greenhouse gas as nitrous oxide entering the atmosphere. In addition, the impact on the environment will be reduced due to the disposal of mining waste, which accumulates in dumps and creates dust, polluting the atmospheric air of the surrounding areas, as well as due to the rational use of the produced space of closed mines, which, with careless closure, intensively pollutes groundwater and creates the risk of disturbance of underground workings and, as a result, may lead to the collapse of the day surface.*

Keywords: *utilization of mining waste, quartzite screening, hydroponics, developed space of closed mines, cultivation of agricultural crops.*

I. INTRODUCTION

According to the Energy Strategy until 2035, it was planned that measures to close or conserve unprofitable mines should be completed by 2025. The issue of mitigating economic, ecological and social consequences will become particularly relevant, which, in particular, can be solved through projects of effective use of the produced mine space and mining waste.

In the process of the production and technological cycle at mining and processing enterprises in Ukraine, about 600 million m^3 (or more than 1 billion tons) of mineral and raw material waste is generated annually, including beneficiation waste 75-80 million m^3, secondary redistribution waste. [2]

Waste-free processing of minerals is one of the priority tasks in the process of their extraction. In particular, this applies to the open mining method, which is accompanied by the accumulation of millions of tons of screenings. Irrational use of land areas for landfills, changes in the landscape and significant dusting of the surface layer of the atmosphere require the urgent application of a set of measures and measures for waste disposal. [3]

The analysis of modern approaches to the utilization of mining waste and methods of using the produced space of closed mines showed that such waste is mainly used in the construction industry [4-6], and the volumes of use are insufficient to neutralize the impact of dumps or slagheap on the environment.

Mining activities not only have a significant impact on the environment during the open pit, mineral extraction, processing and beneficiation stages, but also when the mining enterprise closes and ceases its operations.

It is proposed to increase the level of environmental safety of mining regions due to the use of mining waste as fertilizers for agricultural crops, as well as the produced mining space of closed mines for their cultivation. This approach will reduce the ecological footprint of the process of growing agricultural crops, in particular due to the reduction of the use of fertile arable land and, accordingly, of traditional fertilizers, which are the source of such a greenhouse gas as nitrous oxide entering the atmosphere. In addition, the impact on the environment will be reduced due to the disposal of mining waste, which accumulates in dumps and creates dust, polluting the atmospheric air of the surrounding areas, as well as due to the rational use of the produced space of closed mines, which, with careless closure, intensively pollutes groundwater and creates the risk of disturbance of underground workings and, as a result, may lead to the collapse of the day surface.

II. LITERATURE ANALYSIS

One of the ways to solve the problem of mining waste disposal is the development of technological solutions that will ensure the reuse of waste for the production of products for various purposes. In this way, together with the raw material problem, environmental problems could be solved, which would have a positive effect on the surrounding and geological environment.

The use of mining waste is possible for the production of building materials, the creation of masonry and dams, and the filling of garbage pits. [7]

An alternative use of both waste and fine recycled fraction can be in solutions. They can contain either processed or natural sand, powder obtained during crushing, as a partial replacement for cement. [8]

According to the diversity of the mineral composition of mining waste, it can be used for the production of glass or fertilizers. With the aim of comprehensive disposal and reduction of environmental pollution, studies were conducted on the production of glass ceramics. Sino Steel Maanshan Mining Research Institute [9] has successfully conducted a number of studies on the production of soil conditioning agent or fertilizer using magnetized iron tailings. [10]

The outright closure or abandonment of coal mines is a huge waste of resources and always causes a number of safety or environmental problems. The reuse of a closed mine can make full use of the remaining resources and avoid environmental and geological problems such as greenhouse gas emissions, mine water pollution, and spontaneous combustion of coal seams caused by the closure of coal mines. [11]

The closure of coal mines leaves vast underground spaces that can be used. Closed mines can be reconstructed as underground reservoirs, taking advantage of large areas and low evaporation. Closed shafts in plain areas can be used to fill coal solid wastes such as coal bedrock and fly ash. Closed mine tunnels around cities can be used as underground storage facilities after modification. Closed mines with stable geological conditions can be built as underground oil and gas reservoirs.

Mining sites can be centers for the promotion of geology and mining sciences, in-situ mining, and underground scientific experiments. Mining and cultural resources are usually associated with mining activities and structures, geology and mining engineering, mining history, etc. Mining and geological museum parks in closed mines are one of the effective ways to popularize knowledge about resource protection, energy conservation, emission reduction, and disaster prevention.

Underground space has advantages such as temperature stability (e.g. thermal insulation), insulation (e.g. wind erosion, dust protection, acoustic insulation and vibration damping) and seismic resistance, which are essential for dark matter experiments. Due to its great depth, the underground space in mines makes it a suitable place for explosive tests, scientific tests and especially tests at the mining site, which help to improve the technical characteristics of mining structures and adjust their technical parameters. [12]

In addition to the above-mentioned possibilities of using the produced mine space, coal mines and tunnels can be turned into farms for growing plants. Various crops can be grown in underground farms using hydroponic planters, where plant roots are fed with nutrient-rich water. This water can come from groundwater that is used directly or from water that condenses from the surrounding air. [13]

Plants need only light, oxygen and a nutrient solution containing several different trace elements for growth: potassium, sulfur, iron, magnesium, calcium, nitrogen and phosphorus. Therefore, the roots of crops are immersed in a suitable environment, which allows the plant to develop and bear fruit even better than in the ground. [14]

It should be noted that when grown by the hydroponic method, the plant does not feed its roots in the soil, but in a moist-air, highly aerated water, or solid, but porous,

moist and airy environment, which promotes root respiration, and requires relatively frequent (or constant) drip irrigation with a working solution of mineral salts, prepared according to the needs of this plant. Gravel, crushed stone, etc. can be used as substitutes. [15]

According to recent studies, plants grown hydroponically suffer less from global warming, allowing more plants to be harvested in ideal conditions. Plants grown using this technique are unique because the plants are grown without the use of soil. The amount of water used is much less than in the conventional method. [16]

In a typical hydroponic system, part of the greenhouse is used for harvesting; however, temperature and humidity can affect plant growth and lead to insufficient nutrient uptake by plants. In order to achieve the highest yield, the introduction is carried out in a stable greenhouse environment where the plants are grown taking into account the entire structure.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The object of research is the process of handling mining waste and the produced mining space of closed mines.

The subject of the research is reducing the level of environmental pollution due to the use of mining waste as fertilizers for agricultural crops, as well as the produced mining space of closed mines for their cultivation.

An experimental method was used to achieve the goal. For the experiment, a culture was chosen - watercress, the experiment was carried out using a hydroponic system, that is, instead of germinating the experimental culture in the soil, one of them was grown on water, and the other on an aqueous solution. The seeds were planted in a solution (per 160 seeds, 300 ml of solution) of filtered water with the addition of rock in the ratio of 100 ml:100 g and in ordinary water, which had previously been filtered through a carbon filter. Planting was carried out in containers of the same size, under normal conditions (under direct sunlight, humidity - 40%, temperature - 18°C), where the solution was first poured, and then seeds were laid out on cotton pads - 10 seeds in each hole of the container. The seeds decomposed uniformly and equally. Measurements and photos were taken for five days (Fig. 1).

Quartzite screening was obtained from Tovkachivskiy GZK PrJSC, which develops the Tovkachiv section of the Ovrutskoye deposit. The materials that make up the rock are contained in the following volumes: quartzite – 90–98%, pyrophyllite – 1–9%, ore mineral – 0.3–1%.

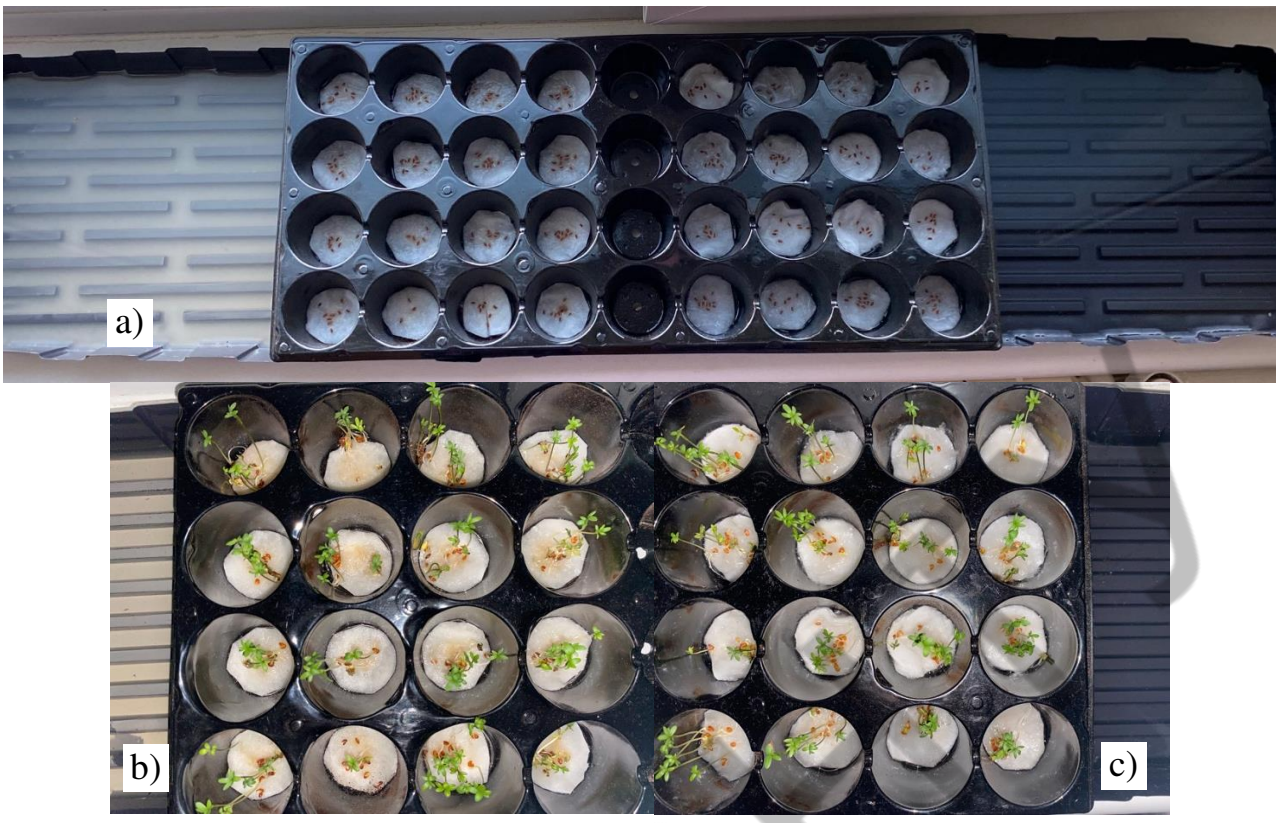


Fig. 1. a – the appearance of the salad on the 1st day; b – the appearance of lettuce on the 5th day, germinated in a solution of filtered water with the addition of rock in the ratio of 100 ml: 100 g (n.u.); c – the appearance of lettuce on the 5th day, germinated in water filtered through a carbon filter (n.u.).

The possible use of mine space to grow plants in it and the parallel use of hydroponic systems are used to reduce complexity and energy costs, while increasing productivity to grow higher quality crops with limited resources.

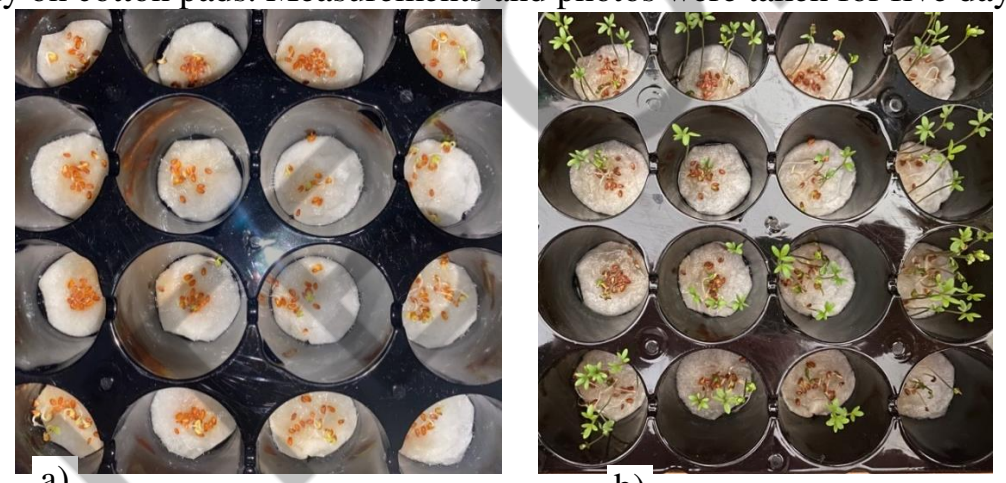
In accordance with this, an experiment was conducted, for which a structure was created, simulating the conditions of the produced mining space of closed mines, for growing experimental crops. In the middle of the chamber, appropriate conditions were created to simulate closed mines, the temperature inside the chamber was 20°C and the humidity was 70-80%.

In addition, a phyto tape was installed, which was the only source of light in the chamber. Since the space of the mine is completely devoid of sunlight, the installation of LED lamps has a positive effect on the plant, as a result of which it begins to grow more actively, the taste improves, and the amount of nutrients and vitamins increases (Fig. 2).

Fig. 2. View of the structure that simulates the conditions of the produced mining space of closed mines, for growing experimental plants.

Since the space in the middle of the mine has a stable temperature and humidity, the purpose of the study is to check the possibility of using the mine space for growing crops in it, in addition, we proposed to use a solution created on the basis of rubble production waste for the hydroponic system in parallel.

The seeds in the simulation chamber were planted in filtered water with the addition of rock in the ratio of 100 ml:100 g. Planting was carried out in containers of the same size, where the solution was first poured, and then the seeds were spread evenly on cotton pads. Measurements and photos were taken for five days (Fig. 3).



a) b)

Fig. 3. a – the appearance of lettuce germinated in a simulated mining capsule of closed mines in a solution of filtered water with the addition of rock in the ratio of 100 ml: 100 g on the 1st day (under a phyto lamp); b - the appearance of lettuce germinated in a simulated capsule, on a solution of filtered water with the addition of rock in a ratio of 100 ml: 100 g on the 5th day of the experiment (under a phyto lamp).

IV. RESULTS

After conducting experiments, an increase in the number of secondary and tertiary roots of the experimental culture, which was planted on a solution of filtered water with the addition of rock in the ratio of 100 ml: 100 g (under phyto lamps), was noticed, compared to experimental plants that were planted on a solution of filtered water with the addition of rock in the ratio of 100 ml:100 g (n.u.).

To determine the level of increase in secondary and tertiary roots, a visual fixation method was used. According to this method, the growth of the root system is 45% (Fig. 4).

A more developed root system of the crop makes it possible to obtain more moisture and nutrients, thereby increasing their endurance and drought resistance.

Fig. 4. The root system of watercress sprouted on: a – a solution of filtered water with the addition of rock in the ratio of 100 ml: 100 g (under a phyto lamp); b - a solution of filtered water with the addition of rock in the ratio of 100 ml: 100 g (n.u.); c – water filtered through a carbon filter.

V. CONCLUSIONS

The chemical composition of mining waste, in particular quartzite screening, was analyzed, and an experiment was conducted to determine the possibility of growing crops using a hydroponic system using a special solution of filtered water with the addition of rock in the ratio of 100 ml:100 g.

An experimental study was conducted to determine the possibility of using the produced mining space of closed mines for growing agricultural crops in it. For the experiment, they chose a universal experimental culture - watercress. The results of the experiments showed that growing watercress using a hydroponic system with the addition of a solution (filtered water with the addition of rock in the ratio of 100 ml: 100 g) under normal conditions and in the dark stimulates an increase in the root system by 45%. A more developed root system allows the culture to receive more moisture and nutrients, thereby increasing its endurance and drought resistance. The obtained results can be explained by the positive influence of silica, which is more than 90% in the composition of rock, on the growth and development of crops.

It is proposed to increase the level of environmental safety of mining regions due to the use of the produced space of closed mines for the purpose of growing crops in it on hydroponic systems. This approach will allow to reduce the ecological footprint of the process of growing agricultural crops, in particular due to the reduction of the use of fertile arable land, and accordingly, of traditional fertilizers, which are the source of such a greenhouse gas as nitrous oxide entering the atmosphere.

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VARIABILITY OF MORPHOMETRIC PARAMETERS OF GLYCERIA MAXIMA POLLEN (C. HARTM.) HOLMB. AS AN INDICATOR OF RADIATION CONTAMINATION OF THE TERRITORY

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Abstract. *The current state of radionuclide pollution of the Chernobyl Exclusion Zone hydro ecosystems is accustomized by the number of radionuclides that entered the environment in the first weeks after the accident, the intensity of their further migration through the catchment area and beyond reservoirs. In stagnant reservoirs, the situation is different; radionuclides were localized in the biogeochemical cycle. An additional factor is that with the intensification of the macrophyte thickets expansion, the oxygen regime of hydro ecosystems worsens, a significant amount of organic matter gradually accumulates and the pH of the aquatic environment decreases. As a result, the processes of the radionuclides desorption are enhanced, primarily* ^{90}Sr*, and their transition to a solubility.*

Therefore, the main task of the research is to monitor the content of radionuclides in the water bodies, bioindicating changes in the state of biota, as well as to determine the level of radiological loads.

Keywords: *bioindication, pollen, aquatic plants, Chernobyl Exclusion Zone, hydro ecosystems*

INTRODUCTION

Topicality of the research is conditioned by the Chernobyl nuclear power plant in April 1986 and the constant use of other nuclear power plants, the influence of radiation contamination on various types of living organisms, including higher aquatic vegetation. Such scientific interest can be explained by the fact that the hydro-ecological situation of the Chernobyl Exclusion Zone has a consistent impact on a wider area, as radionuclides migrate along with surface runoff and groundwater to river systems and reservoirs. Scientists from all over the world conduct permanent studies of radionuclide migration with water flows and accumulation by hydrobionts in order to prevent, preserve and minimize the harmful effects of these negative phenomena in the exclusion zone and inspect the effect of various levels of ionizing radiation on a wide variety of biota inhabiting aquatic ecosystems.

Today, the exclusion zone is an open, planar and large source of ionizing radiation with a complex distribution structure, the presence of various forms of radioactive elements and materials.

The state of freshwater ecosystems is assessed using many zoological and botanical components, including macrophages. The rapid growth rate and high accumulative capacity of higher aquatic vegetations give grounds to consider them as promising for bioindication and remediation studies.

Now in the framework of monitoring programs and concepts, namely "***The concept of comprehensive restoration and development of the territories of the exclusion zone and the zone of unconditional (mandatory) resettlement, which were exposed to radioactive contamination as a result of the Chernobyl disaster for the years 2021-2070***" a study and assessment of the impact of radiation contamination on the state of hydro ecosystems of Ukraine is being conducted. At the same time, the search for the most sensitive criteria for assessing the violation of the stable equilibrium of water communities using bioindication methods continues to be very relevant.

The aim of the research is to establish the peculiarities of the radionuclide contamination influence of the Chernobyl Exclusion Zone on the morphological parameters of macrophyte pollen grains.

As a result of this investigation a number of the **tasks** have been fulfilled like:

- to examine correlation changes in pollen grain length and width *Glyceria maxima* (C.Hartm.) Holmb.;
- to identify the dependence and influence of different doses of radiation load on the morphometric parameters of macrophyte pollen.

The object of our scientific research is viability and variability of morphological parameters of pollen grains of model macrophyte species under the influence of radiation contamination.

The subject of the research is influence of radionuclide contamination of the Chernobyl Exclusion Zone on morphometric parameters of pollen grains *Glyceria maxima* (C.Hartm.) Holmb.

The **scientific novelty** of our research is the dependence of morphological parameters of pollen grains *Glyceria maxima* and various levels of radiation contamination of water bodies in the Chernobyl Exclusion Zone.

The **practical significance** of the research is determined by the correlation between different levels of radiation contamination of CEZ water bodies and the variability of morphological parameters of macrophyte pollen grains. These studies can be used as one of the sensitive criteria for hydrobiological test objects in further bioindication studies of the impact of radiation contamination on the environment of both the Chernobyl Exclusion Zone and the ecosystems adjacent to other nuclear power plants.

CHAPTER 1. LITERATURE REVIEW

Energy consumption is one of the main conditions for the humanity existence; its availability is necessary to meet human needs, increase the duration and improve the standard of living. However, being one of the integral and most important components of human civilization, energy is also a powerful factor of adverse impact on the environment. Nuclear power has many advantages over other areas of this industry, but its characteristic feature is the accessibility sources of radiation risk caused by emissions of radioactive compounds, which under certain conditions can lead to negative impacts both on humans and the environment. The main environmental problems of nuclear power include difficulties in the processing and disposal of radioactive waste. They enter the atmosphere, underground, surface and wastewater, bottom sediments, biota, etc.

1.1. Bioindication of radiological contamination in the Chernobyl nuclear power plant using macrophages

Systematic radioecological monitoring studies of aquatic species of the water cooling reservoir on the territory of the Chernobyl nuclear power plant have been conducted since the early 1990s. In 1993-2013 activity ^{137}Cs in the dominant macrophyte species in the water cooling reservoir was significantly reduced [6]. For *Ceratophyllum demersum* activity decreased from 1500 to 500-600 Bq/kg; for *Myriophyllum spicatum* activity decreased from 5000 to 2500 Bq/kg. A decrease in the activity of radionuclides in these plant species is associated with a decrease in the content of ^{137}Cs in the reservoir, which according to data has decreased by 3 times since the 1990s. Activity ^{90}Sr in macrophytes showed relative stability during the same period. For *Ceratophyllum demersum* activity ^{90}Sr varied in the range of 100-150 Bq / kg; for *Myriophyllum spicatum* 200-250 Bq/ kg; for *Phragmites australis* 500-800 Bq / kg [13, 43-44]

According to Myshkevych E. A. and Shevtsova L. V. the method of using macrophages as bioindicators of radiation contamination is quite effective and promising. They analyzed the current state of data on radioecological monitoring of the aquatic environment using macrophages, on the example of common reeds *Phragmites australis* and checked its effectiveness as a biomarker of radionuclide contamination of the Chernobyl Exclusion Zone reservoir. It is determined that from the degree of contamination of the reservoir with elements ^{90}Sr and ^{137}Cs, the degree of damage to common reeds by gall-inducing arthropods, in particular ticks, *Steneotarsonemus phragmitidis* increases. Studies have shown a high degree of damage by parasitic fungus *Claviceps purpurea* (ergot of rye) and a high level of chromosomal aberrations in the root meristems of macrophytes, using the example of common reeds.

Therefore, this study proves that the absorption elements capacity of radiation contamination by plants is a direct cause of the changes given earlier [28].

An equally important study was conducted by scientists from the Institute of Hydrobiology of the National Academy of Sciences of Ukraine, who determined the doses of absorbed helophyte radiation in the Chernobyl Exclusion Zone reservoirs. They reconstructed the absorption dynamics of radiation contamination doses (^{90}Sr, ^{95}Zr, ^{103}Ru, ^{106}Ru, ^{137}Cs, ^{141}Ce, ^{144}Ce) halophytes of Daleke and Hlyboke lakes, that is, the reservoirs that were most polluted as a result of the Chernobyl disaster. Calculating the radiation dose rate separately for surface and underwater parts of terrestrial plant organs, rhizomes and roots, it was determined that before 1995, the halophyte radiation dose for lake Daleke was 7-15 MGR/year, and for lake Hlyboke – 15-155 IGY/year; in the period from 2016 to 2019, these indicators decreased to 5.6 IGY/year and 7.5 IGY/year, respectively [6, 7].

Also, Ukrainian scientists, led by D. I. Gudkov, studied the effect of radiological contamination on the species diversity of macrophages in the Chernobyl Exclusion Zone. It is determined that the content of radionuclides in the macrophytes' tissues of the exclusion zone is characterized by pronounced species specificity. Maximum concentrations of ^{137}Cs are marked for air-water species, and minimal - for species of the water lily family. The largest ^{90}Sr content is registered for pondweed. Minimum ^{90}Sr activity is marked for sedge and water lilies. Narrow-leaved cattail is characterized

by maximum concentration coefficient of transuranic elements (^{238}Pu et al.). The value of this indicator is on average 6 times higher than the average value of the concentration coefficient for other studied plant species, which allows us to consider narrow-leaved cattail as a specific storage of transuranic elements in the conditions of the exclusion zone reservoirs [9].

Studies of radionuclide content in higher aquatic plants of the near exclusion zone reservoirs of the Chernobyl nuclear power plant showed that the highest levels of accumulation were characteristic of plants in non-flowing and low-flowing waters [8, 9, 10].

So, after the scientific literature review, it can be argued that:

1. Bioindication is one of the most important methods for assessing environmental contamination. Both plants and animals can act as bioindicators.
2. Macrophytes, in comparison with other bioindicators, have a number of advantages, in particular, they have an important indicator value and can be considered as indicators of water quality, the level of eutrophication and water contamination; they are able to accumulate elements of anthropogenic and radiation contamination over a long time, which allows for more accurate studies over a certain period.

CHAPTER 2. OBJECT, SUBJECT, AND METHODS OF RESEARCH

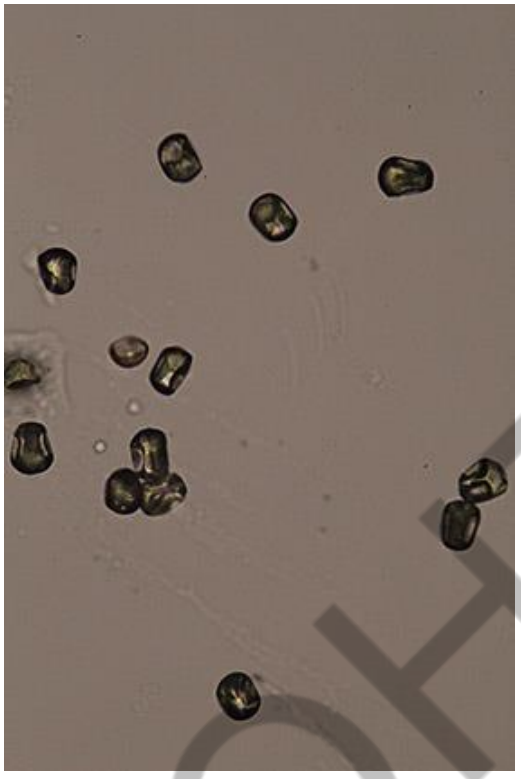
The object of the study is pollen grains of macrophytes of the Chernobyl Exclusion Zone floodplain reservoirs: lakes Hlyboke, Vershyna, Azbuchyn, Yanivskyi backwater and Pliutovyshche, as well as the water cooling reservoir of the Chernobyl nuclear power plant. Floodwaters of the Konka (the right tributary of the Dnipro, the landscape reserve of local importance "Zhukiv Ostriv", which is located in the vicinity of Kyiv) were chosen as controls (water bodies that were not exposed to radiation contamination). The pollen of two types of air-aquatic plants –*Glyceria maxima* was studied. The radioactive contamination level of water bodies was determined from literature sources [8, 9, 10]. For the convenience of analyzing the doses of radiological contamination, the values of the radiation background in the studied reservoirs were reduced to the so-called "dose coefficients". The dose coefficient is a conditional expression of the background concentration rations in the different water reservoirs, where the value of the background load on the "control" reservoirs was taken as:

Table 1.

Water bodies gradation by the level of radiation contamination

Water body	**Dose ratio**	**Contamination level**
water bodies as landscape reserve "Zhukiv Ostriv"	1	null
lk Pliutovyshche	10	low
Yanivskyi backwater	90	minor
water cooling reservoir of the ChNPP	100	minor
lk Azbuchyn	800	high
lk Hlyboke	900	high
lk Vershyna	1000	high

Palynological studies included a comparison of morphometric parameters of pollen grains in reservoirs with different levels of radiation contamination.



General appearance of dry pollen
Glyceria maxima

Fig 1. Pollen morphology of the studied macrophytes under a microscope (magnification 40x)

From 300 to 1000 pollen grains were analyzed (depending on the type of macrophytes), the study was carried out in the range of 70-80 repetitions of the microscope field of view.

The morphological studies of pollen grains were conducted with the help of AxioVision Rel.4.8 software for image acquisition, processing, and analysis (fig.2).

Statistical methods. Initially, the data array was processed in the Microsoft Office Excel 2013 table processor. The results were converted using standard methods of variation statistics (mean – average, min–max – minimum and maximum values were calculated). The indirect ordination method was used to analyze the obtained indicators.

CHAPTER 3. RESULTS

Among the main indicators that determine the stability of a species are pollen viability and seed quality [33, 67]. The male gametophyte is the most sensitive to the action of toxic ingredients. This is showed in the sterility of pollen grains increase and in their fertility decrease; under the influence of unfavorable factors, morphological diversity of pollen grains is observed, the formation of shriveled, destroyed, giant grains, which serves as an indicator of toxic and mutagenic effects [51, 55]. *Glyceria maxima* – is a type, which is able to accumulate the most radioactive elements in its biomass among macrophytes (primarily – ^{137}Cs) [19].

State of local populations *Glyceria maxima* reservoirs with different radioactive loads according to morphometric parameters of pollen grains

Morphometric studies of individual pollen grains of *Glyceria maxima* have shown that with an increase in the background radioactive load, their sizes decrease and the range of individual grains within the sample increases (fig. 4).

Pollen grain lengths at the control area of the landscape reserve "Zhukiv Ostriv" are the largest (indicator varies from 26.79 to 42.16 μm). The length of *Glyceria maxima* pollen grains selected in the reservoir with the highest values of radioactive contamination of the lk Vershyna is the smallest, and the range of the pollen length parameter varies from 15.70 to 33.46 μm. Common variability in the length of pollen grains is observed in the Yanivskyi backwater, lks Azbuchyn and Hlyboke at the highest average value of 30.62 μm per lk Azbuchyn. On lk Pliutovyshche with minimal radiation contamination has a significant range of length indicators from 23.60 to 53.75 μm. Moreover, this locality of the exclusion zone is characterized among all by the highest average pollen length of 33.21 μm. And the lowest value is inherent in lk Vershyna – 28, 69 μm.

Regarding the width of the pollen, the overall situation of the spreading indicators is somewhat different. The largest spread is inherent in the sample from the lk Azbuchyn, where the width varies from 13.28 to 35.22 (μm). The highest average value is inherent in pollen grains collected in the landscape reservoirs of the "Zhukiv Ostriv" – 27.72 μm and the lowest – 22.99 μm – on the lk Azbuchyn.

Consequently, with an increase in the background radioactive load, the spread of morphometric parameters of pollen increases. In terms of average length and width, higher values are also inherent in areas with lower doses. With an increase in radiation contamination, pollen grains of different types in shape and size are formed in plants. At the same time, the decisive factor in influencing the size of pollen grains is the substantial contamination of the water body - by 800-1000 times) (fig. 5).

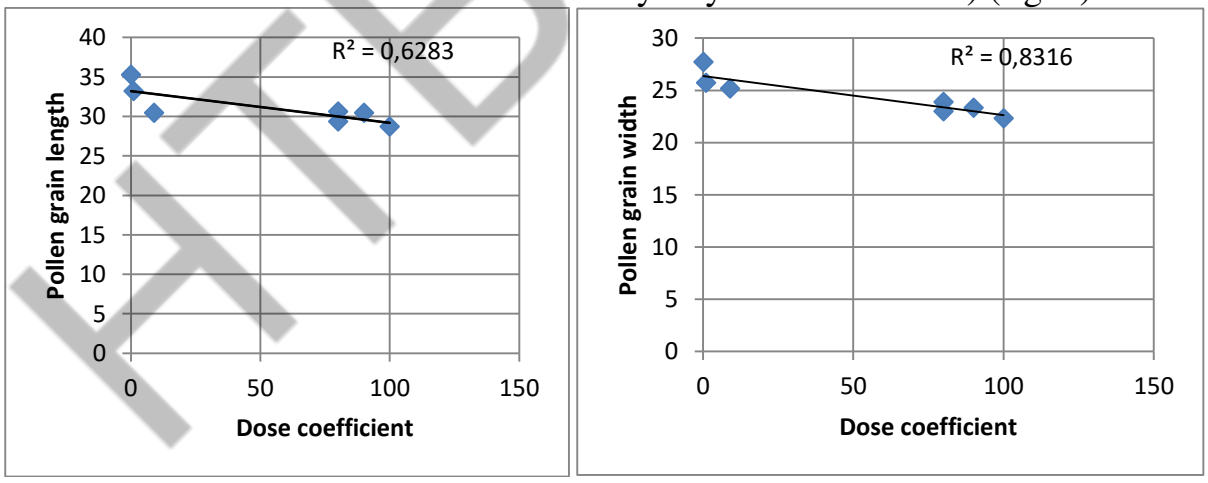


Fig 5. Dependence of morphometric parameters *Glyceria maxima* from the amount of radioactive contamination (dose factor ×10)

In the coordinates of the pollen length and dose ratio, an inverse linear association is observed between them. The approximation confidence interval is 0.63, and the correlation coefficient is 0.79. These indicators show a high association between these indicators.

A similar association is observed in the coordinates of pollen width and dose ratio. The approximation confidence interval is 0.83, and the correlation coefficient is 0.91.

The shape of pollen grains (the ratio of length to width) also correlates (there is a direct linear association) with the level of radiation contamination (fig. 6). Drastic discrepancies are observed at small doses at the control site of the landscape reserve "Zhukiv Ostriv" on lk Pliutovyshche and Yanivskyi backwater. The approximation confidence interval is 0.29, and the correlation coefficient is 0.53. These indicators show a moderate association between them.

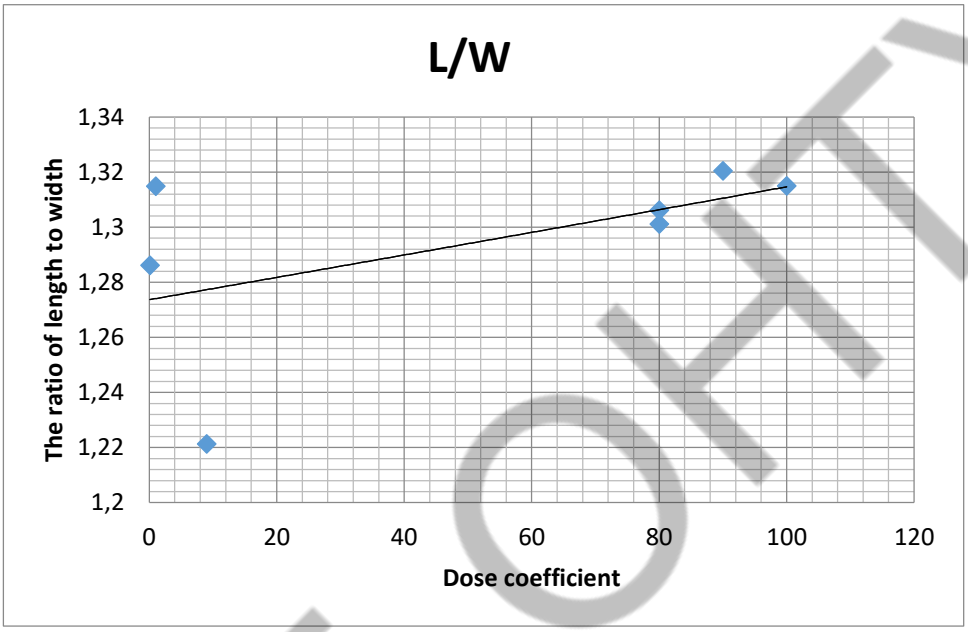


Fig. 6 Correlation analysis of morphometric parameters of pollen grains *Glyceria maxima* with different levels of radiation contamination

CONCLUSIONS

1. In the course of conducting a palynological study to identify the dependence of changes in the morphological parameters of pollen *Glyceria maxima* from the level of radiation contamination of the Chernobyl Exclusion Zone reservoirs, where they grew, a link was established between changes in the size of pollen grains and the proportion of sterile ones from the level of radiation contamination, which allows using pollen from the studied model macrophytes as bioindicators not only in the exclusion zone, but also near other nuclear power plants.

2. Morphometric studies of individual pollen grains *Glyceria maxima* showed that with an increase in the background radioactive load, their dimensions decrease: in the coordinates of the pollen length and dose coefficient, a high inverse linear association is observed between them (in *Glyceria maxima* for length – the approximation confidence interval is 0.63, and the correlation coefficient is 0.79; for width – the approximation confidence interval is 0.83, and the correlation coefficient is 0.91).

3. The range of morphometric values of individual pollen grains within the sample increases with increasing radiation load, and pollen grains that are heterogeneous in shape and size are formed, which also affects the viability of pollen.

4. The negative impact on both the viability and size of pollen grains begins with very low levels of radiation contamination. As the dose increases, the viability decreases, the average size decreases, and the range increases. The most significant radiation contamination of the reservoir is likely to affect the size of pollen grains – 800-1000 times compared to the control.

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6. TOURISM, HOTEL AND RESTAURANT BUSINESS

APPLICATION OF INNOVATIVE INFORMATION TECHNOLOGIES IN THE TOURISM INDUSTRY

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Abstract. *This article analysis of innovative information technologies (IT) implementation in the tourism industry. Also, the tourism industry analysis, statistics, trends, data and forecasts using latest information from UN World Tourism Organization (UNWTO) are carried out in this paper. The following researches methods were used in this paper: analysis of the statistical data, synthesis, logical method, monographic method, comparative analysis, etc. The analysis in this research is based on data from the latest reports of UNWTO and on examination the opinions of experts from the tourism industry.*

Keywords: *tourism industry, UNWTO, information technologies, global distribution system, geographic information systems, computerized network system.*

I. INTRODUCTION

Today, tourism is one of the highest growing sector in global economy due to the steadily growing demand for tourist services. Moreover, the international tourism industry is one of the three world's largest export industries, following the oil industry and the automobile industry.

According to the UN World Tourism Organization (UNWTO) on the development of world tourism in 2022, there were more than 900 million international tourist trips worldwide, twice as many as in 2021. However, by the pre-pandemic 2019 level, global tourism has recovered by only 63%. [1].

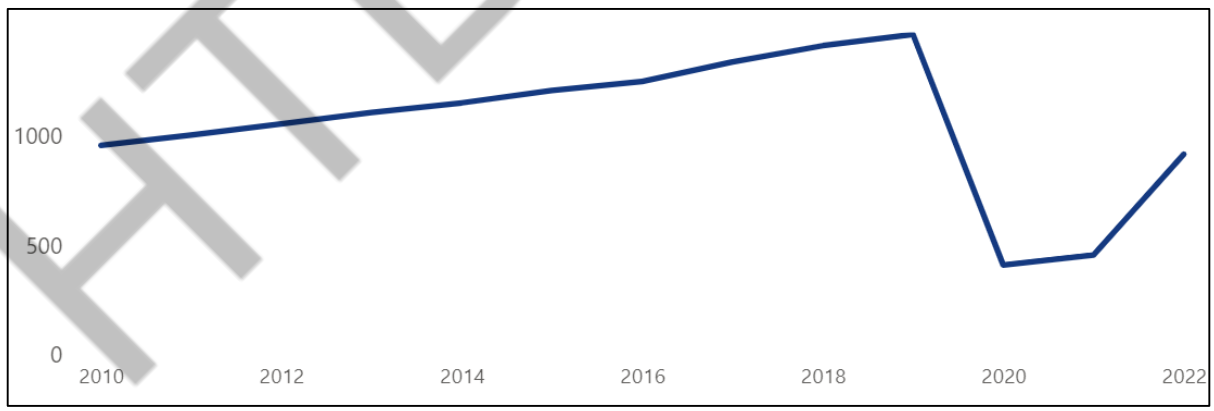

Fig. 1. International tourist arrivals – global indicators, million
Source: [1, 2]

According to UNWTO report: "The highest growth was observed in the Middle East, where international tourism in 2022 was 83% of the level of 2019. The growth of tourist flows is caused in particular, by the Expo in Dubai and the FIFA World Cup in

Qatar. Europe is in second place, where the figure reached almost 80%. In Africa and the Americas, the recovery was about 65%. And in the Asia-Pacific region, where many destinations maintained entry restrictions, the number of foreign tourist arrivals was only 23% of the pre-pandemic level" [1, 2].

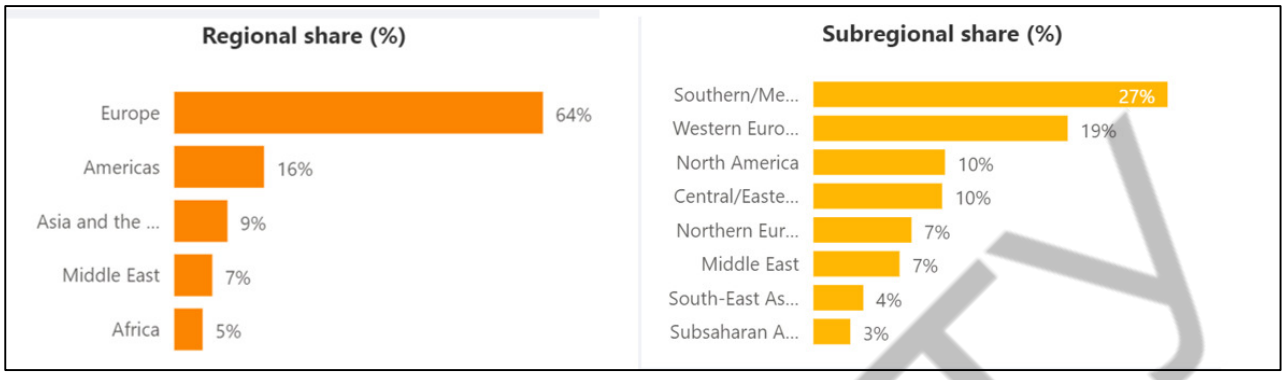

Fig. 2. Global indicators of UNWTO, %:
a) Regional share b) Subregional share.
Source: [2]

According the data from UNWTO, in some destinations, revenues from international tourism exceeded the pre-pandemic level: for example, in Turkey - by 40%, Romania - by 25%, in Mexico and Portugal - by 15 and 13%, respectively.

The development of tourism in current conditions is impossible without appropriate modernization of tourist infrastructure. It assumed, besides the construction of modern roads, airports, hotels, the widespread use of information technology (IT). Information technologies are actively being introduced in the sphere of tourism, their use is an essential condition for successful work, the guarantor of efficiency, reliability, accuracy, effectiveness of management decisions in this area.

II. ANALYTICAL REVIEW OF THE LITERATURE

Many articles, including scientific ones, have been written on this topic.

A lot of recent papers focused on the application of IT in tourism [5, 6, 7, 8, 9, 10, 11]. The paper of the Poland scientists from Wrocław University of Economics [11] discusses the level of information and communication technologies application in the tourism sector. The study covers small and medium-size hotels (SMEs) and travel agencies which dominate the tourism industry worldwide. The article draws experience from the tourism industry in one of the most popular tourist destinations in Poland − Lower Silesia.

Many authors apply modern research methods in their works and obtain interesting results which is very useful for the elaboration of policies in the field of tourism. For example, Australian scientists (Sarath Divisekera from College of Business and Van Khanh Nguyen from Victoria University, Melbourne, Australia) in their article examine innovation processes in tourism in the context of Australian tourism enterprises. To analyze the innovation process, they elaborated a coherent conceptual framework based on the existing literature. Using a longitudinal database and a logistic regression model, the relationship between the inputs or determinants of

innovation and two widespread outcomes of tourism services innovation and marketing innovation are examined. The authors of this article hope that the results of this study will be useful for policy and strategies to improve the innovation capacity of the tourism business in the country [9].

In recent years, many articles and blogs related to the use of GIS in tourism have appeared in a separate new topic [4].

Also, an interesting aspect is the research on smart tourism in the context of tourism information services [11]. Four Chinese scientists (Yunpeng Li from School of Business Administration, Capital University of Economics and Business, Beijing, China; Clark Hu Department of Hospitality Management, Southern Taiwan University of Science and Technology, Taiwan, China; Chao Huang from Miyun College, Capital University of Economics and Business, Beijing, China; Liqiong Duan from Information Center, China National Tourism Administration, Beijing, China) examine the concept of Smart Tourism in their article. For the Chinese tourism market, smart tourism is a new trend that has a significant impact on tourist destinations, businesses, and tourists themselves. According to their analysis, smart tourism is becoming increasingly popular in China. The definition in this research emphasizes that smart tourism as a personalized support system for tourists in the context of information services and inclusive technology. This paper compares the characteristics of both traditional tourist information services and those included in smart tourism.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The purpose of this research is to analyze the implementation of information technology in the tourism industry using the latest data and information from the most well-known organizations and research in this field.

The object of this research is the tourism industry.

The subject is the application of innovative information technologies in this industry.

The following researches methods were used in the presented article: analysis of the statistical data, synthesis, logical method, monographic method, comparative analysis, etc.

The analysis in this research is based on data from the latest reports of UN World Tourism Organization (UNWTO) and examination the opinions of experts from the tourism industry.

It should also be noted, that the author of this article participated in student internship program in organization that specializes in GIS and was involved in different projects related to the elaboration of geographic maps.

IV. RESULTS OF THE WORK

Tourism today is a global computerized business, involving major cross-border transportation, hotel chains and tourist corporations around the world. Due to information technology, contemporary tourism services are becoming more flexible, more attractive and accessible to the simple consumer.

The tourism industry is complex and requires the application of innovative technologies, starting with using of widespread word processing, spreadsheets and

databases to specialized software products that provide automation for a single travel company or hotel, and global computer networks and satellite navigation systems.

Internet Global Computer Network

The Internet Global Computer Network is worldwide system of storing and transmitting information that interconnects computer networks of different levels, such as - states, regions, cities, different organizations, etc. and based on the network protocol stack TCP / IP.

For every tourism company of any size the connection to Internet and availability of browser programs [12], such as:

- Internet Explorer,
- Google Chrome,
- Opera,
- Mozilla Firefox,
- Microsoft Edge,
- Apple Safari,
- DuckDuckgo,
- Chromium,
- Epic,
- Vivaldi,
- Brave,
- etc.

e-mail clients [13]:

- Outlook Express,
- The Bat!,
- Netscape Mail,
- Microsoft Outlook,
- Mailbird,
- Thunderbird,
- eM Client,
- Kiwi for Gmail,
- etc.

IP-telephony programs [14]:

- Viber,
- Telegram,
- Messenger,
- Skype,
- Zoom,
- RingCentral,
- etc.

All these tools are necessary for active using the email, direct booking and online interaction with the client. Also, this assumes the expansion of information about the travel agencies in Internet network, such as: own website with the list of services, information, price list, photos and other useful information.

Global Distribution Systems

Global Distribution System (GDS) is a computerized network system owned or operated by a company that enables transactions between travel industry service providers, mainly airlines, hotels, car rental companies, and travel agencies.

The most well-known representatives of Global Distribution Systems are:

- AMADEUS - one of the top ten travel technology companies in the world,
- WORLDSPAN is a provider of travel technology and content and a part of the Travelport GDS business. It offers worldwide electronic distribution of travel information, Internet products and connectivity, and e-commerce capabilities for travel agencies, travel service providers and corporations. Its primary system is commonly known as a Global Distribution System (GDS), which is used by travel agents and travel related websites to book airline tickets, hotel rooms, rental cars, tour packages and associated products. Worldspan also hosts IT services and product solutions for major airlines [15].
- GALILEO is a computer reservations system (CRS) owned by Travelport,
- SABRE is a leading software and technology company that powers the global travel industry,

At the beginning such systems were developed for reservation of air tickets, but later they also included the possibility of reservation of hotel rooms, sea cruises, car rent, etc.

Internet Distribution System

The Internet Distribution System (IDS) provide travel reservation services to private clients:

- Booking.com,
- Priceline.com,
- Orbitz.com,
- HRS.com,
- Expedia.com,
- Travelocity.com,
- Hotels.com,
- etc.

Geographic Information Systems

Geographic information system (GIS) is a multifunctional instrument that combines tabular, textual, cartographic, business, demographic, statistical, land, municipal, address and other information. Thus, GIS technology is a modern computer technology for mapping and analyzing real-world objects as well as events that happen on our planet. GIS includes systems for collecting, storing, analyzing, and presenting coordinate-addressed information. GIS allows to create and modify: electronic maps, topographic plans, systems of tourist and recreational areas management, cadastre, etc.

GIS can help where spatial information and information about objects in specific locations in space is used. The idea of GIS is the ability to link descriptive information, such as digital and textual information to a specific territory. Therefore, GIS technology plays a central role in the tourism industry.

The most powerful mapping & spatial analytics technology available is Esri's GIS mapping software. The most used software products from ESRI Inc. are:

- ArcInfo,
- ArcView,
- ArcCAD,
- etc.

Also most commonly used:

- MapInfo,
- Autodesk,
- AutoCAD MAP,
- MAPGuide,
- GeoGraphare,
- etc.

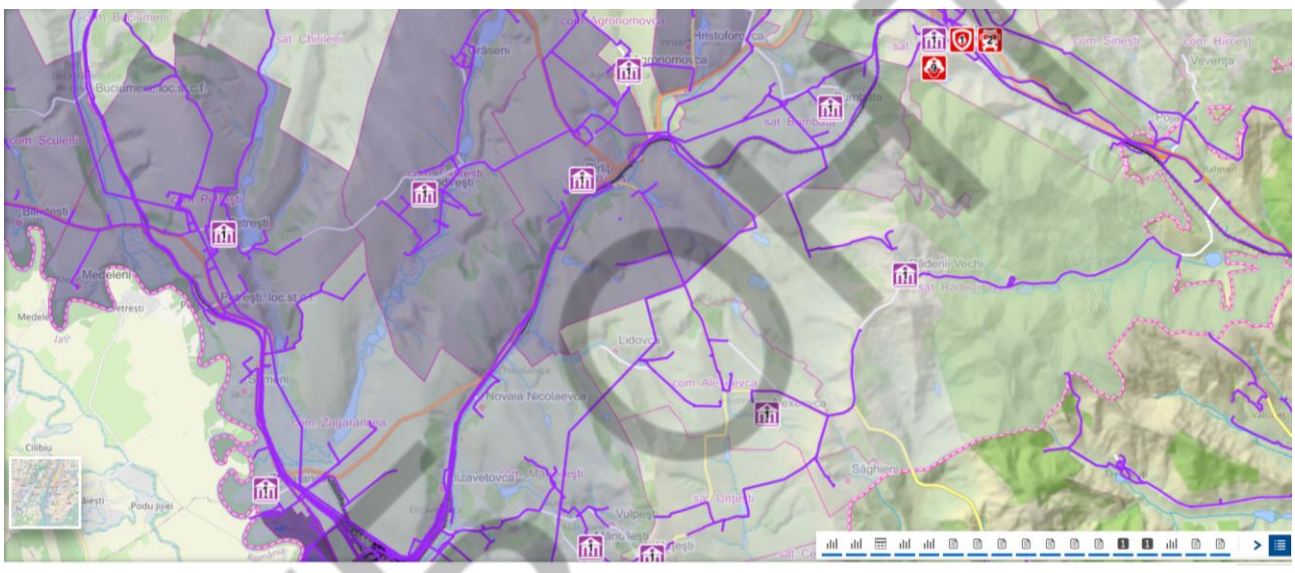

Fig. 3. The first visual example of the application of GIS technology in the tourism industry.
Source: [3]

According to Sagar Bhatia [4]: "GIS not only provides information on tourist attractions, but it is a database of geographical conditions, transportation, accommodation, ethnic groups of the population and more. GIS produces thematic maps which can help tourists understand their destination in a better and detailed manner."

The resulting spatial attribution maps of municipality Chisinau are as follows:

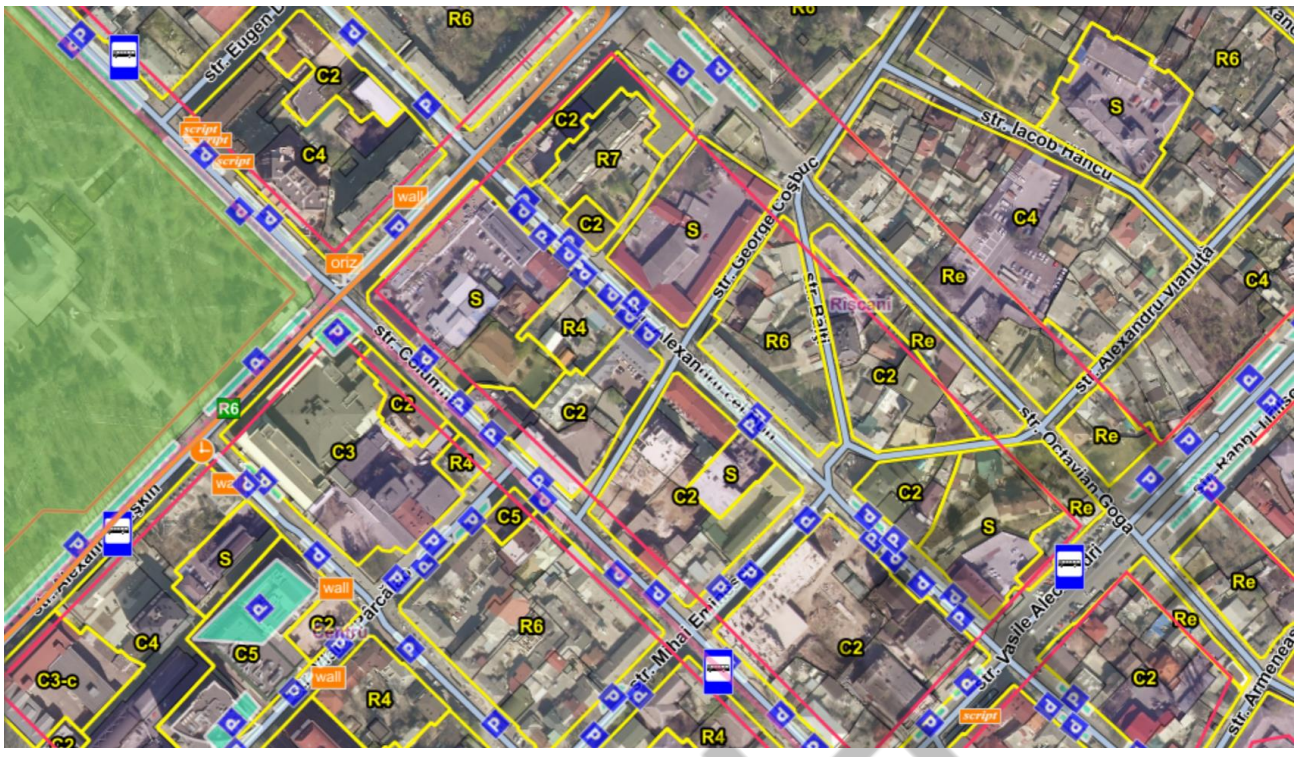

Figure 4. The second visual example of the application of GIS technology in the tourism industry.
Source: [3]

V. CONCLUSIONS

Tourism industry is more than other industries uses specific information, which contains the information about the travel, recreation, tours, tour operators, services, living conditions, etc. The opportunity to analyze information allows to choose the only correct decision and to ensure the best possible selection of services according to individual requirements and possibilities. According to the analysis which is carried out in this research, author can conclude that today, absolutely all organizations working in the tourism industry successfully use information technologies in their work.

After the decline in this industry due to the spread of the Covid pandemic in the world and according to the forecast of UNWTO experts on the beginning of this year: "In 2023, the situation for international tourism will be better. We expect the growth of the industry even taking into account economic problems, continuing geopolitical uncertainty and the possible introduction of new restrictions due to COVID-19. Demand for domestic and international travel will be high and allow some destinations to fully recover from the pandemic." [1, 2] Experts in the field believe that much will depend on the resumption of trips by Chinese tourists, as China was the largest outbound tourism market in the world until 2020. In particular, their return will have a strong positive impact on the situation in neighboring Asian countries.

However, according to the latest data from the UN World Tourism Organization, 32 countries have imposed special restrictions related to the coronavirus epidemic in China. These are mainly Asian and European countries. In particular, Japan, South Korea, India, the United States, Spain, Italy and many other countries require such

passengers to negative test for coronavirus or confirm vaccination. According to Italian authorities, more than half of the 212 passengers on a plane arriving in Milan from China in late December were infected with the Coronavirus [1, 2].

Regarding the implementation the innovative information technologies in tourism industry, the experts believe on the extension of special software products which are intended to help the employees in this area, as well as for simple users.

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DEVELOPMENT OF INCLUSIVE TOURISM IN UKRAINE TO IMPROVE THE QUALITY AND COMFORT OF LIFE OF UKRAINIANS

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This scientific work is devoted to studying the relevance of inclusive tourism in Ukraine. The work analyzes the current state of the Ukrainian population. It was concluded that the number of people with disabilities would increase significantly after the war. Also, according to the survey, it was found that people with disabilities support the development of inclusive tourism and want to include it in their rehabilitation program. The rapid demographic aging of the Ukrainian population due to declining birth rates and super mortality was highlighted.

Based on the official document of the Cabinet of Ministers of Ukraine, «On Approval of the National Strategy for Creating a Barrier-Free Space in Ukraine for the Period up to 2030» the main problems were identified, the solution of which will contribute to the development of inclusive tourism in Ukraine. However, given the difficult economic situation, it was concluded that it would not be possible to achieve the goals set in the project by 2030.

In the course of the work, three projects of European countries aimed at improving the state of inclusive tourism throughout Europe and the world were considered. It was determined that these projects could be useful for Ukraine and help solve existing problems.

Finally, based on a thorough analysis, several recommendations were presented to create a sustainable basis for developing inclusive tourism in Ukraine in the future.

Keywords: *tourism, inclusive tourism, people with disabilities, overcoming barriers, society, needs, accessibility.*

I. INTRODUCTION

Inclusion is a principle of organizing life in a society that allows people to participate in various aspects, regardless of their appearance, origin, gender, or health status. This principle is especially important for people with physical and mental disabilities, as it allows them to feel that they belong to public life and are fully included.

Inclusive tourism, or accessible tourism, means that all travelers can use tourism services without restrictions and on equal terms. Exceptional attention is paid to travelers with special accessibility needs, whether mobility or visual or auditory accessibility.

The basic principle of inclusive tourism is accessibility and universal design. Accessibility means equal access to infrastructure, transportation, information, and communication, and universal design means designing with special needs in mind while meeting the needs of all categories of people. Examples of universal design include contrasting information signs, convenient placement of switches, sockets, and

door handles, low thresholds, satisfactory width of doors, city paths and alleys, high-quality lighting, and the absence of steps at the entrance to public transport.

The development of accessible tourism is essential not only for people with disabilities. Introducing a universal design will make it easier for parents with children, pregnant women, the elderly, travelers with heavy luggage, and those who do not understand a foreign language to travel. Thus, inclusive tourism is suitable for everyone.

II. LITERATURE ANALYSIS

In the course of the work, some Internet sources were used. The main ones are news articles [1-5], from which information was taken to analyze the statistics of the population of Ukraine. In particular, the current population of Ukraine, the number of disabled and pensioners.

Also, the official document of the Cabinet of Ministers of Ukraine, «On approval of the National Strategy for Creating a Barrier-Free Space in Ukraine for the Period up to 2030» was used, from which the critical problems in the implementation of inclusive tourism in Ukraine were highlighted.

From the work of domestic scientists Slavitskaya L.A.and Boyko M.V., information about the factors hindering inclusive tourism development was taken. On the site ofthe European Network of Accessible Tourism, information about the best practicesof European countries was taken from several articles [8-12].

Erasmus+ information about theimplementation of exchange programs in Ukraine during the war was taken from the site dedicated to the educational program.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The study aims to form recommendations for developing inclusive tourism in Ukraine based on the analysis of statistics of the Ukrainian population and the European experience in inclusive tourism.

To achieve the goal, the following tasks were solved:

- Studying the statistics of the population of Ukraine
- Highlighting the main problems in the implementation of inclusive tourism in Ukraine
- Studying the achievements of European countries in the field of inclusive tourism
- Forming recommendations for the development of inclusive tourism in Ukraine

The object of study: inclusive tourism

The subject of the research: factors that influence the relevance of inclusive tourism

This work is based on theoretical research methods, including description, analysis, and induction. In addition, an empirical method, such as a questionnaire survey, has also been applied.

The theoretical value of this study is to summarize the factors influencing the relevance of inclusive tourism in Ukraine today.

The practical significance of the work is to make recommendations for developing inclusive tourism in Ukraine.

IV. RESULTS

4.1 Studying the statistics of the population of Ukraine

According to experts, at the end of 2022, the population of Ukraine amounted to 43,385,749 people. In 2022, the population of Ukraine decreased by approximately 158,501 people. Given that the population of Ukraine was estimated at 43,544,250 at the beginning of the year, the annual increase was -0.36% [1].

Before the conflict began, about 2.7 million people with disabilities in Ukraine, 200,000 of whom were children. But even then, according to unofficial data, it was known that there were much more people with disabilities, about three million. This was explained by the fact that it is much easier to establish their number in large cities and regional centers than in villages, especially those remote from bus and railway stations. The final figure can only be discussed after the survey [2].

In recent years, new categories of disabled people have emerged in Ukraine, such as ATO veterans and people displaced from the occupied territories. After 11 months of the war, the number of disabled people increased significantly. After the war ends, the number of disabled people will almost double.

Given the growing number of people with disabilities in Ukraine, inclusive tourism can be a powerful means of rehabilitation for them. Earlier, the Cherkasy Regional Center for Medical and Social Expertise of the Cherkasy Regional Council, together with regional public organizations of disabled people, conducted a survey among people with disabilities on the development of inclusive tourism as a form of rehabilitation. The questionnaire included ten questions, which 2883 people with disabilities answered.

The question "Do you consider active rehabilitation useful?" was answered positively by 88.6% of respondents.

The question "Do you want to engage in active rehabilitation?" was answered positively by 89.6% of respondents.

The question "Would you like to engage in various types of tourism that have a health, social, and rehabilitation character?" was answered positively by 96.6% of respondents.

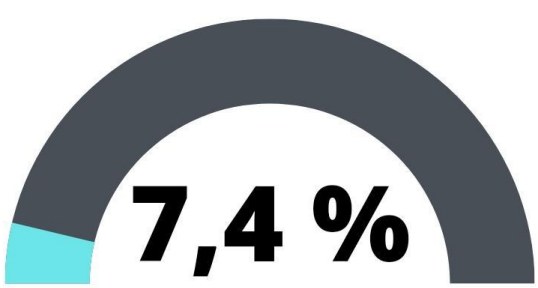
To the question, "Do you consider it necessary to include inclusive tourism as a type of social, psychological, and physical rehabilitation in the individual rehabilitation program for a disabled person?", 75% of respondents answered positively.

According to this survey, it was found that people with disabilities, in the vast majority, want to actively engage in these types of tourism actively, taking into account the development and implementation of inclusive rehabilitation and social tourism as one the active types of repair and want to include it in the individual rehabilitation program (IRP) [3].

Pensioners should be mentioned separately, as they belong to a group of people with a high need for comfort and accessibility, so inclusive tourism is also relevant for them. In the partial year 2022, the number of pensioners decreased by 114,878 people to 10.73 million, including 6.5 million women (60.8%) and 4.2 million men (39.2%) [4]. That is, today, approximately 24.7% of the population of Ukraine are pensioners.

Ukraine has one of Europe's highest population "aging" rates. The reason for this is the rapid decline in the birth rate, which is why the proportion of people aged 60 and

older is growing simply due to the reduction in the number of children. However, this indicator is also affected by the high mortality rate among men of working age between 30 and 60. In demography, this is called "supermortality". The main reasons for this are difficult working conditions, war, and road accidents, in which, according to statistics, 75% of the victims are men, lifestyle, etc. [5].



Of the 2.7 million disabled people in Ukraine, 7.4% are children (Fig. 1.)

As of 2022, 24.7% of the population of Ukraine are pensioners (Fig. 2.)

Fig. 1. Diagram with infographics. Percentage of children with disabilities from the total number of persons with disabilities in Ukraine

Fig. 2. Diagram with infographics. Percentage of pensioners in Ukraine in 2022

Fig. 3 Diagram with infographic. Statistics of people with disabilities in Ukraine

4.2 Highlighting the main problems in the implementation of inclusive tourism in Ukraine

The European Union notes considerable problems with people with disabilities in Ukraine. Thus, the European Commissioner for Human Rights, Thomas Hammarberg, has repeatedly stated that the rights of disabled people are violated in Ukraine [6].

The problem mainly lies in the lack of special equipment that allows people with disabilities to move around and lead a whole life. And while EU countries have long had special design rules and regulations in place, without which no building is accepted by municipal authorities, in Ukraine, developers seem to be successfully circumventing these rules.

This is why the Cabinet of Ministers of Ukraine approved the National Strategy for Creating Barrier-Free Space in Ukraine until 2030 on April 14, 2021. The strategy aims to create an unhindered environment for all groups of the population, to ensure equal opportunities for everyone to exercise their rights and receive services on an equal footing with others by integrating physical, information, digital, social, civil, economic and educational barriers into all areas of public policy.

The document highlights the main problems. Among them, it is noted that most of the public transport (buses, trolleybuses, trams), as well as intercity, international road, and rail connections, are outdated and inaccessible, making it impossible to transport people with disabilities and other low-mobility groups (no ramps, no equipped places for people with low mobility, no signs, no sound signals, no captioned information, etc.) The reason for this is the lack of an effective system of monitoring and control in the field of accessibility.

The next problem is the insufficient level of up-to-date statistical data on the accessibility of physical environment and transport, which complicates the process of formulating and implementing the state policy in the field of accessibility. In addition, due to the lack of professional and independent monitoring of accessibility at the national level, society is not sufficiently informed about the state of physical barrier-free accessibility in Ukraine. Currently, there is no mechanism for monitoring the creation of conditions for unimpeded access by enterprises, institutions, and organizations for persons with disabilities. The reason for this is the imperfect legal and regulatory framework.

The last problem mentioned in the document indicates contradictions between existing fire safety requirements, state standards, regulations, and technical specifications, which complicates implementing provisions to create an unimpeded living environment for people with disabilities and other low-mobility groups. Some of the requirements of the state building codes, which regulate accessibility issues, differ, and contradict each other. Their presentation format is difficult for professionals of different levels of experience to understand.

The reason for this problem is the insufficient number of qualified specialists in urban planning, architecture, and transport in terms of accessibility. There is also a lack of a certification system for specialists to confirm accessibility skills [7].

Earlier, to address the issue of inclusive tourism, an initiative was launched to create tourist routes through historical sites in Ukraine. However, the project still needs to be implemented for several reasons. The first is the underdeveloped infrastructure, with many places, especially museums, not equipped with ramps or handrails for people with disabilities. The second is the need for more qualified personnel working with this category of people. The Strategy for Creating Barrier-Free Space in Ukraine is designed to solve these problems, build proper infrastructure and provide quality training [8]. However, given the difficult economic situation and the destruction of many cities and infrastructure due to the war, more money must be spent to implement the strategy. As a result, Ukraine will not be able to achieve its goals by 2030. The project will most likely be frozen indefinitely.

4.3 Studying the achievements of European countries in the field of inclusive tourism

In Europe, the topic of inclusion is very relevant, so in 2006, the European Network for Accessible Tourism (ENAT) was established. It is a non-profit association of tourism businesses, organizations, and individuals from the private, public, and civil society sectors. It aims to evaluate best practices and provide and support services and

products for accessible tourism in Europe. The list of honorary members of the association includes the World Tourism Organization (UNWTO) [9].

ENAT's website, in the Projects and Best Practices section, presents many examples of best practices that help make travel and tourism accessible to all.

Among them is the Pantou Accessible Tourism Guide, created initially as a data collection tool for the European Commission's study of accessible tourism in Europe in 2014.

It lists travel service providers that can offer accessible travel services to customers with special access needs, the elderly, people with disabilities, families with young children, and people with chronic illnesses. Since the end of March 2017, Pantou's directory has been open to including accessible tourism providers from any country, not just Europe. Suppliers can register for free.

The suppliers listed on Pantou provide a wide range of tourism services, including accommodation, facilities, transportation, tours, venues, and attractions designed to be inclusive and accessible to people with disabilities, chronic illnesses, or other special accessibility needs.

Pantou's mission is:

1. To compile a comprehensive list of suppliers that provide services for developing «Tourism for All», initially in Europe and, from April 2017, worldwide.

2. Promote accessible tourism providers in Europe and worldwide.

3. Promote the development of accessible tourism supply in the Member States of the European Union and other countries [10].

The Pantou.org website does not currently offer any services that could be provided in Ukraine [11].

Fig. 4. The logo of Pantou online guidebook of accessible tourism

The TAD project is worthy of note. TAD is a project funded by the European Union's Erasmus+ program under Key Action 2: Cooperation for innovation and exchange of best practices aimed at accessible tourism. By the way, Ukraine is one of the partner countries of the Erasmus+ program. This project offers a VET (Vocational education and training) course for learners who want to work as external consultants or employees in the tourism sector. The course provides essential knowledge on accessible tourism and introduces EU policies, concepts, principles, and methods to improve the tourism environment and services to serve visitors with special access

requirements. The course content is curated by ENAT, the European Network for Accessible Tourism, and combines online learning and classroom/seminar sessions.

The trainee will receive a TAD certificate upon successful completion of this specialized course (nominally 80 hours, including classroom training, supervision, and tourism business training sessions).

The TAD project aimed to make Europe a truly accessible tourist destination for all visitors by training tourism and hospitality professionals through a work-based learning approach, looking at the problem from a new perspective.

The project results are now being published as Open Educational Resources (OER) to increase access to training and qualifications for all. In addition, they will be disseminated to VET providers and stakeholders at local, national, and European levels [12].

Fig. 5. Logo of TAD educational program
Fig. 6. Logo of Erasmus+ educational program

SENTOUR CONNECT EU project. Facilitating low-season tourism exchanges in Europe and encouraging older people to travel. With the growing European market for older people, senior international tourism can be essential in developing low-season tourism.

Professional organizations working mainly on the domestic, structured national market of older people will try to stimulate the supply and demand of transnational tourism for older people.

The main objectives of the project are:

1. Stimulate the demand and supply of transnational tourism for older people
2. Increase equal access for less experienced travelers aged 55 and older.
3. Support sales and product lines specifically designed to motivate travelers to visit destinations in the low season.
4. Create innovative travel packages for seniors that are affordable and sustainable beyond the period of EU co-financing.
5. Develop cooperation protocols that will support cross-border and intercultural exchanges and programs that reach all categories of older people.
6. Establish and strengthen sustainable European public-private partnerships (PPPs) to promote the creation of a European internal market for older people in the long term by establishing cooperation between private and public organizations in Europe, not limited to the partner's domestic market [13].

In this way, Europe supports the elderly and encourages them to travel and relax. Furthermore, tourism in the low season means that it will be convenient for pensioners

to visit tourist destinations because there will be no significant influx of tourists and no queues.

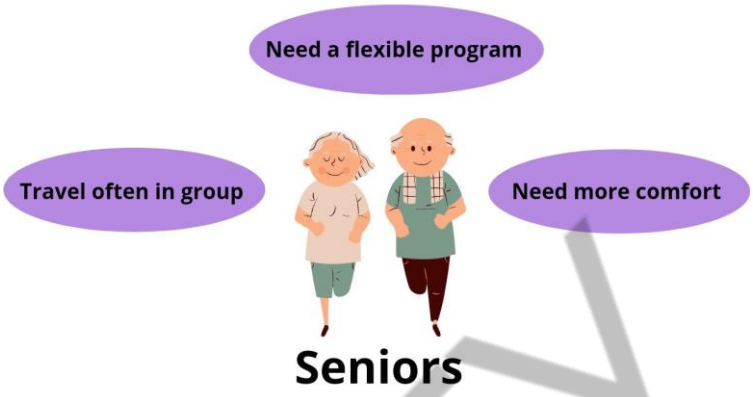


Fig. 7. The logo of the SENTour Connect project

Fig. 8. Visualizing the needs of the seniors

4.4 Forming recommendations for the development of inclusive tourism in Ukraine

Having analyzed the problems of Ukraine, its population and the best practices of Europe in the development of inclusive tourism, I have compiled a list of recommendations that will help in the further development of accessible tourism.

1. Fostering a tolerant society

I believe this is the foundation on the way to creating an inclusive environment. According to the principle of inclusion, all people have equal rights regardless of their appearance, origin, gender, or health status. Everyone is worthy of respect. If the main principle of inclusion is violated, the development of high-quality inclusive tourism is impossible. That is why it is important to create healthy and friendly relations in a society where there is no place for bullying and discrimination.

2. Sharing European experience through educational programs

3. Currently, many educational programs allow people of all ages to receive modern and high-quality education in European countries. Among these programs, we have reviewed TAD, a project funded by the European Union's Erasmus+ program. The Erasmus+ program creates many opportunities for Ukrainians to study abroad. Furthermore, considering the martial law, the European Commission, within the framework of the Erasmus+ Program, has introduced flexible procedures and exceptional measures for obtaining grants for educational and academic (credit) mobility to support Ukrainians who are pupils/students/employees of schools, vocational (vocational-technical) and professional higher education institutions, adult education and for young people from Ukraine since March 2022. Such support provides an opportunity for short-term study/practice or internship/teaching, participation in training and volunteer initiatives abroad. This way, the problem of shortage of qualified personnel in the field of inclusive tourism can be solved [14].Creating appropriate training programs

4. This point is important for employees in the tourism industry. Employees of hotels, catering, transportation, museums, and recreational facilities should improve their skills to provide quality services to people with disabilities and the elderly.

5. Improving conditions in sanatoriums and health centers

6. Sanatoriums are popular in Ukraine. Among the most popular are: Truskavets, Morshyn, Myrhorod, Berehove, Solotvyno, Kosyno, and Polyana. People with health problems and pensioners usually prefer these recreational facilities. Therefore, it is necessary to improve the living conditions and services for clients with special needs.

7. Reducing prices for some tourist services

8. This item refers to accommodation, catering, transportation, and entrance tickets to tourist attractions. Affordable tourism means affordable prices. If possible, tourism service prices should be reduced to increase demand among tourists of different groups.

9. These are the main points that do not require huge investments, but their implementation can become a reliable foundation for the further development of accessible tourism.

V. CONCLUSIONS

My research proved the relevance of inclusive tourism for Ukraine, given the current realities, the increasing number of people with disabilities, and the accelerating pace of population aging. Furthermore, because inclusive tourism has several dozen varieties, it creates a wide variety of rehabilitation services and enhances human development.

According to the survey data, it can be concluded that people with disabilities perceive inclusive tourism as a modern and promising type of rehabilitation that may include medical, psychological, pedagogical, physical, and sports rehabilitation activities.

In addition, based on the analysis of Ukraine's fundamental problems and European achievements in the field of accessible tourism, a list of essential recommendations was compiled that can help to develop inclusive tourism in Ukraine.

This type of tourism is beneficial for everyone, as it allows us to meet the needs of everyone, regardless of age or health status. Inclusion should become a way of life for Ukraine, especially since we must consider it after hostilities end.

After the war, Ukraine will embark on a long path of revival. First, we will have to rebuild the destroyed cities and infrastructure. Applying the principle of universal design in the reconstruction of our country will help to avoid the old problems with accessibility and open the door to a comfortable future. To make life comfortable not only when traveling but every day.

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CONCEPTUAL MODEL OF MARKETING TECHNOLOGIES FOR CUSTOMER SERVICE BASED ON AN INDIVIDUAL APPROACH

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Abstract. *The article considers a conceptual model of marketing technologies for customer service based on an individual approach, which is represented by six blocks: goal setting, analysis, listening, technology, management and control, correction and implementation. The model is based on the "design thinking" and the values framework. The model is tested on the example of Edem Resort Medical & SPA. The SWOT analysis of Edem Resort Medical & SPA is carried out. The model is evaluated using service performance indicators*

Keywords: *conceptual model, value framework, design thinking, goal setting, performance indicators, SWOT analysis, technology, management, customer, service.*

I. INTRODUCTION

The modern marketing model is based on the perceptions with which a customer perceives a product or service. The conceptual model of marketing technologies is a set of methods and techniques, means of obtaining, processing and handling not only information, but also materials and resources, which will help achieve the planned result. Effective marketing technologies contribute to the analysis and creation of value for the consumer, and form its value. The main technologies are Design Thinking and the Value Proposition Framework. It is the basis for the development of effective marketing technologies for customer service.

II. LITERATURE ANALYSIS

"Design of thinking" was proposed by scientists at the Hasso-Plattner Institute of Design at Stanford (D.school). The essence of the technology is to explore new opportunities for solving customer problems by understanding human needs, developing ideas, and generating them. The stages of technology implementation are compassion, problem definition, idea, prototype, and test [1; 3; 5]. The Value Proposition Framework technology model was developed by Osterwalder A. [1; 4]. The value proposition framework is a technology that promotes a service or product in the value plane, taking into account the needs of the client. This technology is based on the analysis of the relationships between services, actors, and real market needs. It can be used to improve an existing offer, as well as to explore a new one. Thanks to the Value Proposition Canvas, a product or service can be studied through the prism of the preferences and expectations of a demanding customer.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The object of the study is a conceptual model of marketing technologies for organizing hotel customer service.

The subject of the study is Edem Resort Medical & SPA.

Research methods analysis, synthesis, and scientific abstraction are used to study the essence of the conceptual model of marketing technologies for organizing hotel customer service. Methods of comparison and analysis for the dynamics of the capacity utilization rate of collective accommodation facilities and the number of temporary accommodation and catering facilities. Generalization method for drawing up a SWOT analysis matrix for Edem Resort Medical & SPA.

IV. RESULTS

The conceptual model of marketing technologies for organizing hotel customer service is represented by the main blocks: 1. Block of goal setting. 2. Block of analysis. 3. Listening unit. 4. Block of technologies. 5. Management and control unit. 6. Block of correction and implementation of individual customer service (Fig. 1).

The goal setting block has four components: 1. Mission definition. It is necessary to define the purpose and meaning for which the hotel operates, to outline the priority areas of activity and values. A well-chosen mission ensures success in promoting hotel services. All other elements and structures should be consistent with the mission. 2. Define a vision that describes the desired type of hotel in the future with its values. 3. Defining the goal of creating customer service with an individual approach. That is, the justification of the need for the procedure for realizing the mission and obtaining value for the client from using such an offer. 4. Development of a development philosophy. It outlines the quality policy, management approaches, and integrity.

The block of analyzing the current state is typical for hotels that do not have a development philosophy. The listening block is used by hotels that have declared a development philosophy. The technology block involves the use of such technology models as Design Thinking and the Value Proposition Framework.

Performance monitoring should be carried out according to the following indicators [8, p. 158]: 1. Number of visits to the site, number of search queries: measured by analytical systems. 2. Behavior on the site, which objects and buttons are clicked more often: shows how well the site is created (using Google Analytics). 3. Response to the newsletter: how many donors responded to the project information. 4. Statistics on social media: which posts are more liked and which give more return (for example, Facebook analytics). 5. Number of implemented projects. 6. The amount of donor funds raised. 7. Number of partnership projects. 8. Number of publications and mentions in the media (using Brand Analytics). 9. Number of volunteers willing to join the brand. 10. Survey of the audience on the website for satisfaction, what needs to be improved, or if there were any difficulties.

Let's characterize Edem Resort Medical & SPA by blocks.

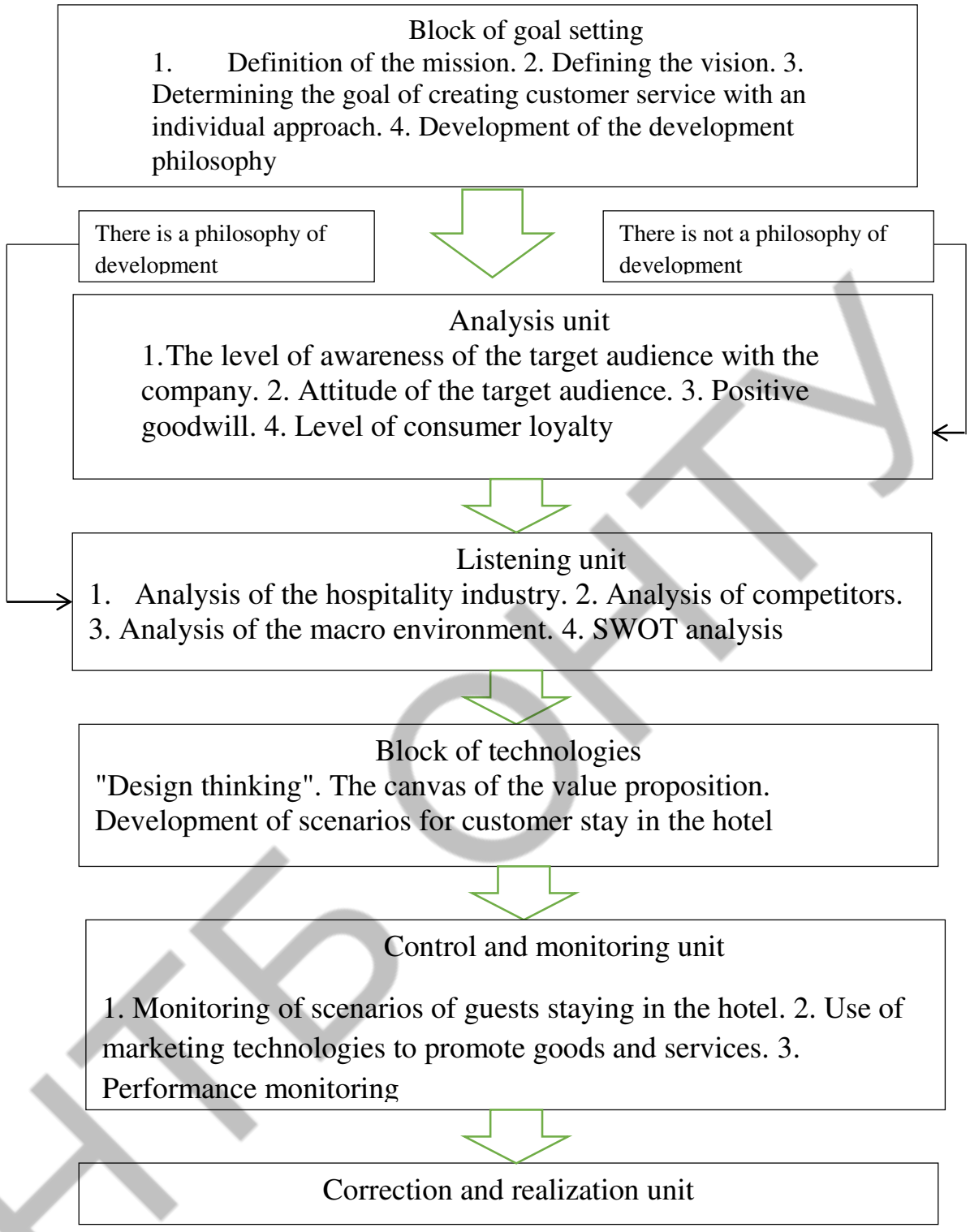

Fig. 1. Conceptual model of marketing technologies for customer service on an individual approach*

* compiled by the author

Goal setting unit. The company's mission is to combine a palace and park complex for recreation and entertainment with a health recovery center. The emphasis of this complex is on relaxation and recovery [7]. The ideal location for this type of enterprise is the shore of a lake with picturesque landscapes, where the complex is located 40 km from the old Lviv. The complex includes a luxury hotel with exclusive

rooms, four fashionable restaurants, five conference and banquet halls, a spa and a health center.

The hotel has 88 rooms of all categories. The elegant interior design is designed in warm colors, with exclusive furniture and modern appliances. Most rooms have a private balcony overlooking the lake or forest. There is an Edem restaurant at guests' disposal. You can taste unique wines in the De Vine Lobby Bar. Another restaurant - Terrace - is located on the lake. The complex also has three luxurious banquet halls on the lake.

Services provided in this complex: sauna, swimming pool, business center, viewpoint, breakfast included, luggage storage, conference room, indoor swimming pool, master classes, wellness treatments, parking, laundry, safe, shuttle service, gym, private beach, Wi-Fi.

The company's vision is to create an institution where everyone can realize their dreams and fulfill their expectations, as well as receive high-quality health and relaxation services.

The purpose of the business is to give customers the freedom to fulfill their dreams and desires, which the hotel can realize. This is how the hotel positions itself "You feel it right away... As soon as you cross the border between the ordinary world and the country of Eden, everything changes somehow. Suddenly, imperceptibly, but dramatically. You get a different mood, different emotions, even different thoughts and memories. The country of Eden is a place of power where you feel the energy filling your mind, body and soul! Years pass, the complex expands, improves, and changes. Now one of the best medical hotels and resorts in Europe, Edem Resort Medical & SPA has grown into a real country with its own traditions and borders. Having received the coveted visa of the Land of Eden, you will be able to take advantage of all the bonuses and privileges available to its residents. The gates of Paradise open for you, where body and soul merge together, filling you with health and inspiration! EDEN COUNTRY ACCEPTS GUESTS ONLY BY PRIOR RESERVATION!" [6].

The development philosophy should be based on the concept of providing high-quality recreational services on an individualized basis in combination with health improvement.

The management of Edem Resort Medical & SPA adheres to the following basic rules and secrets of success: 1.Start individualized service in advance before the guest arrives at the hotel. Study their preferences using social networks, the database of previous stays, and the services they used during their last visit. Develop a "travel map" to give the guest more emotions and pleasure. 2.During remote communication, pay more attention to the client's wishes, provide offers that will be difficult for him to refuse. Create the impression that the offer is created individually for him. Do not interrupt communication with the future guest. 3) A few days before the arrival, send a list of things to take, depending on the type of hotel and what additional services are offered there (swimming pool, bath, sauna, beach, fitness center, spa). 4) Make sure that the guest's positive experience encourages them to share the hotel with the world. This can be done through social media, gadgets, or physically. Do everything to make the client want to tell everyone about your hotel. 5.Participate in the preparation of the guests' holiday. Offer your own, pre-prepared scenario, taking into account all

preferences and nuances. Create the impression of caring for the client. Offer new products based on what was liked last time. 6.Personalized approach to each client. Call and inform them that a celebration is planned and you are waiting for this particular client. Get them interested with your attention and make a good impression. Be creative with the invitation. 7.Use the USP. A unique selling proposition (USP) is an offer that is suitable only for a specific person. When creating it, understand that this offer is suitable for only one person. Edem Resort Medical & SPA is very popular because of its individual approach to each client. Creating certain scenarios before the arrival of guests adds a lot of bonuses to the company. Why does it work? The manager does everything with his heart. The customer's satisfaction comes first, and making money comes second. If you put money first, you can't expect a positive and successful outcome. Self-interest does not win. Guests feel the energy, understand who did their best and who made what efforts. The client will want to purchase more additional services if he is sufficiently satisfied with the services he has already used. More individualized, personalized approach - then the client will be really impressed.

Listening block. Here is the SWOT analysis matrix of Edem Resort Medical & SPA (Table 1). The SWOT matrix describes the relationship between the strengths and weaknesses of the company, on the one hand, and the threats and opportunities in the external environment, on the other. Based on this, the main directions of strategic development of Edem Resort Medical & SPA, in our opinion, should be: search for investors; development of rural green tourism; promotion of energy saving; implementation of sports programs, recovery programs, body cleansing, relaxation; creation of appropriate conditions for leisure.

Table 1. SWOT analysis Edem Resort Medical & SPA *

Strengths	**Weaknesses**
1. Favorable economic and geographical location nearby. 2. Locations on the shore of the lake. 3. Three restaurants, one of which is located on the lake. 4. Located 40 km from the ancient city of Lviv. 5. High professional level of the team.	1. Not all of the territory has developed road infrastructure. 2. The system of using renewable and alternative energy sources is underdeveloped. 3. There is no system of separate collection of solid waste throughout the community.
Opportunities	**Threats**
1. Growing popularity of rural, green, and cultural tourism among the population of Ukraine and Europe. 2. The possibility of using Internet resources to promote the community. 3. Use of non-traditional healing methods.	1. Continuation or freezing of the military conflict in the East of Ukraine. 2. Outflow of qualified personnel outside the community. 3. The Covid-19 pandemic. 4. Difficult political and economic situation in the country.

* compiled by the author

Technology block. "Design thinking involves empathy, which is the first stage. It involves consulting with experts, assessing the physical environment, incentives, and intentions of consumers. The clients of Edem Resort Medical & SPA seek to receive new services at an adequate price. In addition, they want to relax morally and physically, and realize their dreams. When defining the problem, we use observation, abstraction, and study the motives for purchasing services and products. The main motivations for ordering services at Edem Resort Medical & SPA are to relax and realize individual dreams that they cannot get in other similar facilities. Difficulties faced by customers are routine and mundanity, and the desire for change. At this stage, an idea arises that is related to the client's personal expectations. During brainstorming and customer requests, the main areas to be developed in the hotel are identified. In particular, the hotel launched recovery and body cleansing programs, which are important for most clients today. The proposed services are tested among individual customers at a trial price. These services have shown significant demand, so they are highly effective.

The framework of the value proposition involves identifying narrow target groups of consumers. The main target group is young people over the age of 12, with or without families, mostly women and men working in high-paying jobs. Customers cannot travel far from their place of residence and stay away for long periods of time. The next step is to assess the environment in which the client operates. This is mainly a business environment, with overtime, high labor and energy costs. The assessment of the environment of the Edem Resort Medical & SPA hotel is presented in Table 2 and Table 3. According to European and world standards, the capacity utilization rate of collective accommodation facilities should be close to 70 % [12, p. 166]. However, no region of Ukraine has this level of indicator. It is worth noting that it decreased in 2020 compared to 2018 by 35.5 pp, and in 2020 compared to 2019 by 33.3 pp. The consequences of the post-pandemic crisis have a negative impact on the environment of the hotel industry. It shows the effectiveness of investments made in collective accommodation facilities. This indicator is extremely low and declining every year. Therefore, investors do not invest in this market, as investments are very risky.

Table 2. Dynamics of the capacity utilization rate of collective accommodation facilities in 2018-2020 [11; 9]

Region	2018	2019	2020	Deviations			
				2020/2019		2020/2018	
				+/-	%	+/-	%
Ukraine	0,31	0,3	0,2	-0,10	-33,33	-0,11	-35,48
Vinnytsia	0,30	0,29	0,26	-0,03	-10,34	-0,04	-13,33
Volyn	0,35	0,28	0,24	-0,04	-14,29	-0,11	-31,43
Dnipropetrovs'k	0,39	0,30	0,18	-0,12	-40,00	-0,21	-53,85
Donetsk	0,33	0,32	0,32	0,00	0,00	-0,01	-3,03
Zhytomyr	0,30	0,36	0,26	-0,10	-27,78	-0,04	-13,33
Transcarpathian	0,21	0,16	0,18	0,02	12,50	-0,03	-14,29
Zaporizhzhya	0,38	0,35	0,24	-0,11	-31,43	-0,14	-36,84
Ivano-Frankivsk	0,23	0,21	0,21	0,00	0,00	-0,02	-8,70

Kyiv	0,34	0,34	0,21	-0,13	-38,24	-0,13	-38,24
Kirovograd	0,19	0,23	0,20	-0,03	-13,04	0,01	5,26
Luhansk	0,23	0,18	0,18	0,00	0,00	-0,05	-21,74
Lviv	0,31	0,30	0,14	-0,16	-53,33	-0,17	-54,84
Mykolaiv	0,35	0,32	0,28	-0,04	-12,50	-0,07	-20,00
Odesa	0,27	0,28	0,17	-0,11	-39,29	-0,10	-37,04
Poltava	0,29	0,28	0,17	-0,11	-39,29	-0,12	-41,38
Rivne	0,21	0,19	0,13	-0,06	-31,58	-0,08	-38,10
Sumy	0,24	0,23	0,14	-0,09	-39,13	-0,10	-41,67
Ternopil	0,22	0,18	0,10	-0,08	-44,44	-0,12	-54,55
Kharkiv	0,21	0,21	0,15	-0,06	-28,57	-0,06	-28,57
Kherson	0,43	0,35	0,25	-0,10	-28,57	-0,18	-41,86
Khmelnytsky	0,30	0,32	0,18	-0,14	-43,75	-0,12	-40,00
Cherkasy	0,26	0,24	0,21	-0,03	-12,50	-0,05	-19,23
Chernivtsi	0,25	0,26	0,14	-0,12	-46,15	-0,11	-44,00
Chernihiv	0,21	0,25	0,19	-0,06	-24,00	-0,02	-9,52
Kyiv city	0,36	0,37	0,19	-0,18	-48,65	-0,17	-47,22

In Ukraine, in 2020, 0.2 person-days actually provided by collective accommodation facilities accounted for 1 person-day of single capacity per year, in 2019 - 0.3, in 2018 - 0.31. By December 2019, there was a 39.3% increase in the number of temporary accommodation and catering facilities (in 2019 compared to 2010). However, in 2020, the growth rate was only 2.95% (in 2020 compared to 2019). The COVID-19 pandemic and the unreadiness of the hotel and restaurant business to change have a negative impact on operations, slowing the growth of the number of accommodation and catering establishments (Table 2). According to Table 3, it can be concluded that COVID-19 affected the reduction in the number of temporary accommodation facilities in 2020 compared to 2019 by 4.74%, and the activity of hotels and similar accommodation facilities by 5.98%.

Table 3. Dynamics of the number of temporary accommodation and catering facilities in 2010-2020 [11; 9]

Indicator.	**2010**	**2018**	**2019**	**2020**	**Deviations**			
					2020/2019		**2020/2010**	
					+/-	**%**	**+/-**	**%**
Temporary accommodation and catering	50033	61761	69689	71748	2059	2,95	21715	43,40
1. Temporary accommodation	10113	8203	8838	8419	-419	-4,74	-1694	-16,75
- activities of hotels and similar accommodation facilities	4209	4985	5451	5125	-326	-5,98	916	21,76
2. Activities related to the provision of food and beverages	39920	53558	60851	63329	2478	4,07	23409	58,64
- activities of restaurants, provision of mobile catering services	29950	41860	48398	51069	2671	5,52	21119	70,51
- beverage service	5335	6604	7038	7297	259	3,68	1962	36,78

The impact of COVID-19 on food and beverage establishments was insignificant, with an increase of 4.07%. Overall, the growth rate of temporary accommodation facilities slowed by 2.3 times (from 13.6% in 2019/2018 to 4.07% in 2020/2019).

The next stage of the value proposition framework is to identify the "pains" at Edem Resort Medical & SPA. The main problems that need to be addressed immediately are the following: the weak level of development of the YouTube channel, the active use of hidden advertising BTL technology, the lack of event marketing in the activity.

The main benefits that customers will receive from staying at Edem Resort Medical & SPA are: 1) active and passive recreation at the guest's choice. Active recreation can be realized in the golf club, tennis, fithealnh, alpine park, water aerobics, yoga, kinesis, mini-football, Nordic walking, bicycles and quad bikes, power yoga, super-surfing, fly-yoga. Passive recreation can be in the Eden art space: art gallery, medical center, spa, restaurants (Panorama is a temple of healthy organic food, DeVine offers 354 wines and 4 autochthonous varieties from the Bordeaux wine collection, edem is the spirit of romance and classic luxury, Terrace by the lake is a place where you can enjoy the exquisite taste of food); 2) fulfillment of dreams related to the realization of preferences. The main factors of assistance are highly qualified staff who will develop a vacation scenario for you personally and adjust it if necessary. The factors of benefit for customers that Edem Resort Medical & SPA has are: 1) cheaper vacation compared to analogues in other cities, including abroad; 2) close location to the client, lack of customs and other formalities; 3) combination of rest with treatment and sports, rehabilitation; 4) creation of a fairy tale for the visitor and romanticism, which is lacking in everyday life. The main services that are most popular among visitors are: 1. Hotel: economy, standard, superior, single and two-room suites, executive suites, club house, residence on the water.2. SPA: one-day programs (SPA-Day "Anti-age SPA", SPA-Day "Regeneration", SPA-day "Relaxation"), three-day programs (Anti-stress SPA-weekend, Oriental-style weekend, express body recovery, SPA Detox program). 3. Art: art space with artistic elements. 4. Medical center: detox classic, re-energy, fithealth, detox basic, detox light, detox body&mind, anti-stress weekend, productivity program. 5. Sports: tennis, fithealnh, alpine park, water aerobics, yoga, kenesics, mini-football, Nordic walking, bicycles and ATVs, power yoga, super-surfing, fly-yoga. 6. Restaurants: Panorama, DeVine, edem, Terrace by the lake. 7. Golf club: children from 6 years old are allowed to visit the club. 8. Events: weddings, birthdays, conferences, banquets, dating parties

The development of scenarios for customers' stay at the hotel is individually tailored to the client's request, but before arrival, a virtual scenario of their stay is created for each client, which is guided by the staff of Edem Resort Medical & SPA.

Management and controlling unit. Monitoring of the service efficiency is carried out according to the following indicators, which are shown in the table number 3.

Table 3. Performance indicators of Edem Resort Medical & SPA y 2020–2022 *

Indicator	2020	2021	2022
1. Number of visits to the site, number of search queries: measured by analytical systems, units.	14385	15584	1620
2. Behavior on the site, which objects and buttons are clicked more often: shows how well the site is created (using Google Analytics)	Spa&Wellness, price, Sport	Medical Center, price, Spa&Wellness	Price, Spa&Wellness
3. Response to the newsletter: how many donors responded to the project information, %.	58,7	64,7	63,8
4. Statistics on social media: which posts are more liked and which give more return (for example, Facebook for analytics, https://www.facebook.com/EdemResortSpa, YouTube-analytics, https://www.youtube.com/channel/UC7yd6r6G27vtaGYT7pWubkg)	Facebook 23812 users YouTube 280 users	Facebook 24417 users YouTube 315 users	Facebook 24623 users YouTube 321 users
5. Overall hotel rating, points	4,5	4,9	4,7
6. Number of partner projects, units.	15	21	24
7. Number of publications and mentions in the media (using Brand Analytics), units.	78	87	89
8. Surveying the audience on the site for satisfaction, what needs to be improved, and whether there were any difficulties	yes	yes	yes

* compiled on the basis of management accounting data at Edem Resort Medical & Spa and own research.

Thus, in 2022, the performance indicators of the service sector improved slightly. However, the following main shortcomings can be identified: 1) a low number of publications and mentions in the media about Edem Resort Medical & SPA; 2) the social page on YouTube has a meager number of subscribers. The YouTube page has only 321 subscribers, while Facebook has 24.6 thousand subscribers, and 22 thousand subscribers out of the total number react to publications, i.e. only 90.2%; 3) there are only 46 videos on the YouTube channel (16 videos in 2022; 13 videos in 2021, 7 in 2020, 6 in 2019, 13 in 2018, and 7 in 2017); 4) very low activity of discussion of materials posted on YouTube.

Correction and implementation unit. It consists in the development of measures to correct deviations of actual indicators from the planned ones in the form of improving the development strategy, mastering new types of non-traditional health improvement. The company is expanding its activities. In particular, new types of art recreation, sports recreation and health improvement are being developed on the territory.

V. CONCLUSIONS

It has been established that the modern marketing model is based on the perceptions with which a customer perceives a product or service. Marketing technologies are based on the relationships that arise in various areas, marketing, management, production, in each business process using consistent operations, techniques and actions. The main technologies are Design Thinking and the Value

Proposition Framework. The essence of Design Thinking is to explore new opportunities for solving customer problems through understanding human needs, developing ideas and generating them. The value proposition framework is a technology that promotes a service or product in terms of value, taking into account the needs of the client. On this basis, a conceptual model of marketing technologies for customer service based on an individual approach is built. The marketing tools for customer service based on an individual approach are: advertising, sales promotion, public relations, personal selling, Internet marketing, branding, franchising, telemarketing, merchandising. The assessment of Edem Resort Medical & SPA according to the conceptual model of marketing technologies for customer service based on an individual approach allowed to identify strengths and weaknesses, to identify gaps in the hotel's activities.

Subsequently, based on the generalizations and conclusions of the conceptual model, it is necessary to develop a customer service program based on an individual approach in the following stages: determining the target audience of the product; developing a stay plan; creating a product; selecting partners; adding extra services and experiences; expanding the product; promoting the product; packaging the product.

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CAPSULE HOTELS: TRENDS AND PROSPECTS FOR IMPLEMENTATION IN UKRAINE

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Abstract. *The purpose of the scientific work is to investigate the theoretical aspects, ergonomic solutions in capsule hotels, foreign experience, and the practice of implementing capsule hotels in Ukraine. First, the essence of the concept of capsule hotels, the reasons and history of their emergence are highlighted in the scientific work. Next, the features and main ergonomic solutions in capsule hotels are described. In addition, foreign experience in the development of capsule hotels is studied. Then, the paper analyzes the trends in the development of capsule hotels in Ukraine. A general characterization of the capsule hotel "Capsule Hotel Constellation 89" located in Lviv is also made. Finally, on the basis of the conducted sociological survey and the carried out SWOT analysis, the idea of implementing the business project "Capsule Hotel Shangri-La" is substantiated.*

Keywords: *concept, conceptual hotel, capsule hotel, ergonomic solutions, innovations, hospitality, business project, Ukraine's prospects.*

I. INTRODUCTION

Significant growth in the hospitality industry around the world creates positive prospects for the accommodation market. Consumers increasingly prefer hygiene, comfort, economical and budget accommodation when traveling. And various technological advances, ergonomic solutions, and innovations are driving the market growth.

Capsule hotels offer tourists an alternative option for budget and short-term accommodation in megacities. Recently, they have become increasingly popular due to their low cost and greater privacy than, for example, conventional hostels can provide. According to IMARC Group, the global capsule hotel market reached $97.8 million in 2022. In the future, the market is expected to reach $309.9 million by 2028, showing a growth rate of 10.2% [5].

Capsule hotels maximize comfort, which is now a key component of a good trip, especially when you want to relax in private after a busy day. A capsule hotel refers to a compact, unique accommodation facility equipped with basic amenities, which also makes it one of the most affordable.

The new direction of the service can successfully take root in the Ukrainian market, but it requires taking into account the specifics of the target audience, promotion and market positioning.

II. LITERATURE ANALYSIS

The theoretical foundations of conceptual hotels and their classification were studied by O. Shykina, G. Fadeeva [20]. Trends in the development and quality of service of small hotel forms in Ukraine are highlighted in the works of A. Dyakonova, L.

Titomir, K. Zhovtyak [7]. R. Kozhukhivska explored the use of international experience in implementing innovations in the hotel business [9]. Minimalism in capsule hotels is covered by foreign scholars Siyun Chen, Haiying Wei [16]. However, the issues of innovation, technology, and alternatives have not lost their relevance for hospitality companies and require further research on capsule hotels, taking into account industry specifics, modern business conditions, and current challenges.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The object of research is the features of the development of capsule hotels, ergonomic solutions implemented in capsule hotels.

The subject of the study is the theoretical and practical aspects of the functioning of capsule hotels, based on the study of foreign experience and implementation in Ukraine.

The research methods are primary methods for studying sources and collecting information; historical method and analysis and synthesis in the process of studying the peculiarities of capsule hotels development in Ukraine and the world; systematic approach in the study of ergonomic solutions in capsule hotels; brainstorming method and heuristic method in the development of the business project "Capsule Hotel Shangri-La".

IV. RESULTS

4.1. The concept of capsule hotels: the essence and history of its origin

Today, one of the most unique and interesting types of hotels you can find while traveling is a capsule hotel. They have become a trend in the hospitality industry, as they are a cheap analog of regular hotels, and a more improved and comfortable option than hostels.

The first capsule hotel in the world, Capsule Inn Osaka, opened in 1979 in the Kansai region of Japan, on the island of Honshu, and has been attracting guests ever since. The concept of creating a capsule hotel was the brainchild of Kisho Kurokawa. He was a prominent Japanese architect and one of the founders of the post-war Japanese architectural trend – Metabolism. It was this trend that became the basis for the ergonomics of hotels and buildings in Japan in general, and the factor that led to the creation of this architectural trend was the larger population of people in Japan [12; 16]. In 1972, he designed a residence called "capsule house K". It was an early conceptualization of a revolutionary idea that he later turned into a commercial version. This is how the world's first capsule hotel was born [6; 20].

Unfortunately, such a novel idea in the 70s was only available for men. Today, almost all modern capsule hotels are shared, and to be competitive with the new capsule hotels in Osaka, the rules and interior of the Capsule Inn were updated to give it a fresh look and be able to compete. Today it is called New Japan Umeda [6].

In general, capsule hotels have small rooms. The long cube-shaped capsules are usually 1.25 m wide, 2 m long and 1 m high. Thus, they are not exactly suitable for standing or sitting. The idea is to provide people with enough space to feel comfortable and get a good night's rest, without unnecessary glamor that takes up space and costs money [13].

Capsule hotels are intended for students and business travelers who are not particularly demanding in terms of comfort and are not ready to overpay for amenities they will not use. The second group to whom such hotels are suitable is budget tourists, especially among the millennial generation. It should be noted that in recent years, the target audience that is particularly interested in capsule hotel accommodation offers has tended to grow rapidly.

4.2. Ergonomic solutions in capsule hotels

Ergonomic solutions, as well as design solutions, are the results of creative activity when creating capsule hotels (Fig. 1). They have a large number of extremely small rooms (capsules) to provide cheap and basic overnight accommodation for guests who do not need the services offered by traditional hotels [21].

Fig. 1. Ergonomic solutions in capsule hotels
Source: photo taken from open Internet sources

The main ergonomic solutions in capsule hotels are generalized:

1) The size of a standard capsule is 2 x 1 x 1.25 m, which does not require much space to create such a hotel. The capsules are made using metal, wood and hard materials such as plastic and fiberglass. The capsules are integrated into the hotels, arranged in rows and equipped with a locker, alarm clock, charging sockets and single or double beds.

2) LED lights next to the guest capsule make it easier to find it, as all capsules look exactly the same.

3) The light inside the capsule can be changed and there is also a TV remote control.

4) Quality capsule hotels include a small TV in the capsule, as well as free Wi-Fi access; curtains or doors in the capsule that can be closed to make the capsule more private. They also have their own air conditioning controls inside the capsule to make your stay as comfortable as possible.

5) Capsules can only provide a place to sleep, as they are quite small. In these hotels, luggage is stored in a luggage room. Each guest has their own locker for their belongings so that everything is private and safe.

6) Showers and toilets are shared in capsule hotels, but they are comfortable and cozy. And if the guest is concerned that he or she will not feel comfortable climbing into the capsule in pajamas at night, it's for nothing, as these hotels also offer separate groups of capsules for men and women.

Thus, the concept of capsule hotels is widely implemented by entrepreneurs in many countries, such as the Great Britain, China, Hong Kong, Japan, where it may also be known by another name, such as "pod hotel" [14; 22].

4.3. Foreign experience in the development of capsule hotels

For many years, capsule hotels have remained popular. After all, traditional capsule hotels are designed as cheap accommodation for those who do not want to pay for a standard hotel room. But the experience has changed dramatically as capsule hotel owners compete to provide guests with the most stylish and luxurious experiences. That being said, newer, more elegant and spacious capsule hotels don't necessarily come cheap. Recently a few premium and themed capsule hotels have been opening around Tokyo, Kyoto and Osaka with slightly higher prices.

Whether they are located in prime locations (for example, Tokyo Narita Airport) or offer unique features (for example, a view of the Mediterranean Sea), some capsule hotels can even compete with traditional hotels in terms of price. However, you can still find many cheap capsule hotels all over Japan (Japan is the birthplace of capsule hotels, so there is a large concentration of them in this country), and not only that, some capsules cost as little as $15 per night.

Therefore, Table 1 presents the top 10 best capsule hotels from around the world in terms of price, originality, and convenience, with consumption prices ranging from UAH 490 to UAH 3 686 per night [3; 19].

In general, a standard capsule is a fiberglass unit built around a single size futon mattress. The typical capsule includes a TV and Wi-Fi internet inside, and a privacy curtain or door to cover the entrance. In addition, sheets, blankets and pillows are provided, and each capsule is also equipped with a light.

All other facilities at the capsule hotel, such as washrooms, toilets and showers, are shared by guests. Many capsule hotels also usually have large communal baths where you can enjoy a soak before bed. In addition, they often have restaurants, vending machines, laundromats, internet kiosks, lounges, entertainment rooms, game rooms, libraries, etc. The procedure to stay at a capsule hotel is basically the same in most capsule hotels. Capsule hotels often provide English check-in instructions at the counter or may have English-speaking staff.

Table 1. Top 10 best capsule hotels in the world

Capsule hotel	Features of the capsule hotel	Price	Rating on Booking.com
Nonze Hostel (Pattaya, Thailand)	It combines rustic, modern and vintage design, and offers free Wi-Fi, a 24-hour reception and a choice of single and double capsules. The air-conditioned pods are equipped with their own sliding doors, reading lamps and power outlets.	from UAH 490	8,7 / 10
Dream Lodge (Lavender, Singapore)	The hotel is decorated with inspirational quotes. The connection to Lavender Airport makes it popular with tourists. Bicycle rental is also available.	from UAH 2 322	8,9 / 10
Book And Bed Tokyo Shinjuk (Tokyo, Japan)	This is a hotel where you can sleep in bookcases. These unique capsule hotels look and function like a bookstore. Here you can find the perfect book and then lie down in your capsule, hidden in a bookcase.	from UAH 1676	7,4 /10
Nine hours (Minato-ku Akasaka, Japan)	The hotel has a sophisticated design, very convenient pointing arrows on the floor, which make it seem like you are flying away in a spaceship. The name is based on the fact that 9 hours is enough for a stay: you spend 1 hour washing your face, 7 hours sleeping, and 1 hour getting ready in the morning.	from UAH 1174	8,0 / 10
CityHub (Amsterdam, Netherlands)	Guests can make their own drinks in the hotel bar. Using the mobile app, guests can control their room and communicate with CityHosts. Guests will stay in a separate sleeping cabin with a king-size bed. The bathroom has a tropical shower.	UAH 2849	9,0 / 10
YOTELAIR (Gatwick Airport South Terminal, UK)	The Japanese-style hotel offers free Wi-Fi and a 24-hour front desk. The capsules are equipped with a music system, relaxing lighting and a work desk. All rooms have a TV. Bathrooms are fitted with a monsoon shower.	UAH 3686	9,1 /10
First Cabin Akasaka (Akasaka, Japan)	This is a Japanese chain consisting of about a dozen establishments and offering four different rooms - from premium economy class capsule cottages to standard first class rooms.	price is not speci-fied	8,2 / 10
Petra Capsule Hostel (near Petra, Jordan)	Perched high above the city, the capsules offer incredible views of Wadi Musa and are just a short walk from the archaeological site of Petra.	from UAH 700	9,6 / 10
The O Pod (Tel Aviv, Israel)	The hotel offers capsules of various sizes, from traditional stacked capsules to full-length mini-rooms. The capsules have doors.	UAH 1605	8,4 / 10
The Pod Sydney (Sydney, Australia)	Each room has a king-size bed, reading lamp, chargers and air conditioning. There is a shared kitchen.	from UAH 1539	9,0 / 10

Source: compiled by the author based on [3; 19]

Thus, among Japan's many ingenious inventions, capsule hotels have probably attracted the most attention worldwide, including in Ukraine. After all, the smallest hotel rooms in the world have made overnight stays affordable. There are many different types of capsule hotels at different price ranges.

4.4. Trends in the development of capsule hotels in Ukraine

Despite the decline in tourist traffic, the Covid-19 pandemic, and the full-scale war in Ukraine, new areas of the hotel business are emerging, and the hospitality industry continues to develop despite all the challenges. Innovative capsule hotels have become increasingly popular in recent years. The trend for capsule hotels came from Japan. It was unlikely that such small rooms would be to everyone's taste. However, recently their popularity has been growing due to their low cost and greater privacy than conventional hostels can provide. The trend of blending business with leisure activities on business is becoming increasingly popular, especially among the millennial generation (Bleisure Travel by Millennials) [7; 10].

It should be noted that in recent years, the target audience that is particularly interested in capsule hotel accommodation offers has tended to grow rapidly. The reason for this is the increasing mobility of the population, but, most importantly, it is a decreasing willingness to pay for real but unnecessary comfort. At the same time, capsule hotels compare favorably with hostels, primarily because of their privacy and technology.

In 2019-2022, a number of interesting hostels and hotels in Ukraine were opened and are currently under construction, including the A-Hostel capsule hotel, The Tower Hostel, Sheraton Kyiv Olimpiyskiy, Ibis Red, the futuristic Monotel Space (Monotel capsule hotel chain), and the world's first hostel built from two decommissioned subway cars in Podil, Kyiv.

Gett Sleep Boryspil became the first representative of capsule hotels in Ukraine. A large number of innovations have been implemented in the new project of the capsule hotel chain Monotel, which has already launched its first capsule hotel in Kyiv [18]. Monotel is a hotel of the future for those who value sleep in their aura and technology at a reasonable price. There is everything you need for business travelers and residents of a big city: monocapsules for sleep, personal lockers, separate showers and toilets, luggage storage camera, silent service. In addition to individual sleeping capsules, there are also capsules for couples. The capsule is opened using an electronic key. As Monotel is a hotel chain, the franchise project envisages opening several more hotels in Kyiv, Lviv and Odesa [1; 8].

As of January 1, 2023, there are 9 capsule hotels in Ukraine, including 3 capsule hotels in Lviv – AntiHostel Forrest [2], Capsule Hotel Constellation 89 [4], Lounge Capsule Hotel [11]; 1 hotel in Boryspil – GettSleep; 5 capsule hotels in Kyiv – A-Hostel, Maidan Monotel, Monotel Khreshchatyk, Monotel Velodrome, and AV-2 Capsule Hotel [1]. Unfortunately, after the start of Russia's full-scale invasion of Ukraine, the AV-1 Capsule Hotel in Kyiv ceased to function.

It is advisable to pay attention to a worthy representative – Capsule Hotel Constellation 89 [4]. This capsule hotel is located in Lviv, at 21 Shevchenka Street (Fig. 2), 1.7 km from Lviv Railway Station and 2.1 km from Rynok Square. Hotel mission: if you want to spend your time in Lviv comfortably and plunge into the atmosphere of space travel, Capsule Hotel Constellation 89 is the best option.

It offers a restaurant, a shared kitchen and a shared lounge, as well as free Wi-Fi throughout. The capsule hotel also offers a terrace and a 24-hour front desk. An à la carte breakfast is served every morning at the capsule hotel.

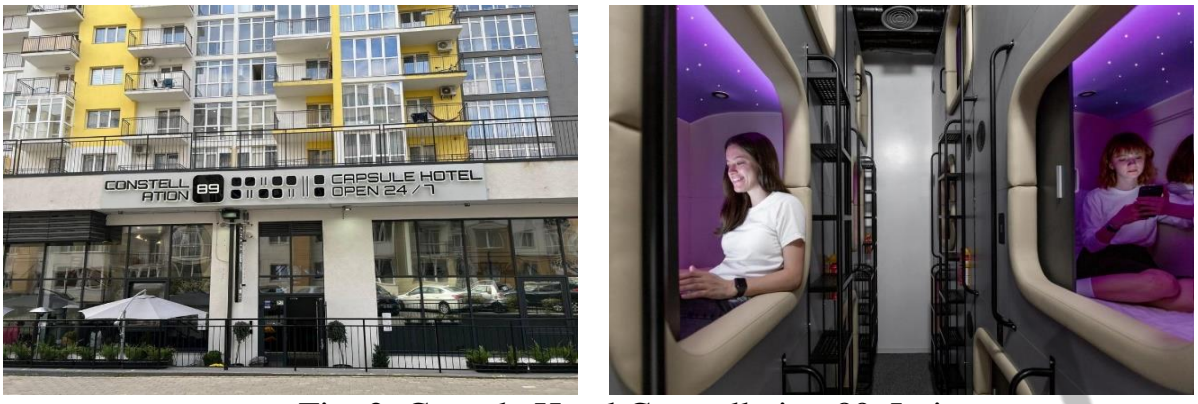

Fig. 2. Capsule Hotel Constellation 89, Lviv
Source: photos taken from the official website of Booking.com

Since the name of the hotel "Constellation" means "Constellation" in English, the design naturally corresponds to the name. The capsules themselves are designed in the form of space shuttles (Fig. 3). In the middle of the capsule there is lighting in the form of a night starry sky. The overall interior of the capsule hotel has a minimalist design, including corridors, a restroom, a reception, etc. They are decorated in classic black, white, and gray colors, with green accents in the form of live plants.

Fig. 3. Design of the capsules of the Capsule Hotel Constellation 89
Source: photos taken from the official website of Booking.com

Upon check-in, guests receive a personalized locker, access card, crocs and a towel. There is Wi-Fi coverage, snacks and drinks. The snack area is open from 9 to 22. You can also purchase breakfast: or include it in your reservation. On the territory of the hotel (there is a kitchen) you can prepare your own food. The hotel has two separate areas – a lounge for leisure, work and a quiet area for sleeping. Additional services provided by the hotel: snack bar, restaurant, terrace, board games, jigsaw puzzles, ironing service, laundry service (extra charge).

The price of staying in such a hotel ranges from UAH 315 to UAH 824 in the off-season, and can reach a price of UAH 600 to UAH 1 216 on holidays (prices include taxes and fees). And if you are an experienced traveler who constantly uses booking sites, then, for example, the discount on booking for non-holidays can even reach 43%, i.e. a single capsule room for men and women (mixed) without breakfast can cost UAH 180 instead of UAH 315.

As for the hotel's rating on booking sites and reviews, we compared ratings from different sites. If we consider the rating of the hotel from Booking.com, it is 9.2/10, which indicates a high quality of service in this hotel. Guests from Booking.com rated the staff and price-performance ratio at 9.5/10, cleanliness at 9.2/10, comfort and quality of free Wi-Fi at 9.1/10. The lowest score out of all 9.0/10 was given to location and amenities. As for the ratings on the Airbnb booking site, consumers rated the hotel at 4.68/5, which is also an excellent result. Guests who used this site liked the arrival aspect of the hotel the most, with 4.9/5 points, followed by communication, accuracy and value for money at 4.8/5, and cleanliness and location at 4.7/5. The latter parameter is almost identical to the rating on the parallel site, which indicates that most guests do not like the location of the hotel.

Analyzing the reviews from both sites, most tourists like the Capsule Hotel Constellation 89, especially its uniqueness, design, high-quality internet and breakfast. As for the negative feedback, some guests did not like the staff who did not meet the customer's needs, as well as poorly working ventilation during daytime blackouts, which causes a musty smell.

Thus, analyzing the Capsule Hotel Constellation 89 in Lviv, it is worth noting that it confirms that an economy hotel, essentially a hostel, can surprise with the quality of services and design, and it does not have to be an almost destroyed building that has been used by more than 1 million tourists and has not been renovated for 20 years. It is possible to provide cheap, clean and comfortable accommodation without spending large sums of money on its construction. The Capsule Hotel Constellation 89 is a perfect example of how ergonomic, small hotels care more about nature and quality of service. Therefore, opening a capsule hotel is a deliberate and financially sound decision, especially for beginners who have decided to enter the hospitality industry.

4.5. Justification of the implementation of the business project "Capsule Hotel Shangri-La"

The implementation of a capsule hotel is a profitable and fairly good business in terms of payback, which will also be very modern, ergonomic in its plan and original in its idea. Therefore, an author's business plan for opening a capsule hotel has been developed, in which you can make sure of the success of your capital investments.

Since the opening of capsule hotels as a business is quite new for Ukraine, this concept is suitable for large transport hubs and large cities, where rooms for short stays are in demand. Such an idea is very suitable for its implementation in Lviv. Lviv is a city in the western part of Ukraine. The historical center of Lviv is included in the UNESCO World Heritage List. The city has the largest number of architectural monuments in Ukraine. In 2009, Lviv was awarded the title of the Cultural Capital of Ukraine. The city periodically occupies prominent places in the ratings of tourist and investment attractiveness.

SWOT analysis [17] was used to study the idea of implementing a capsule hotel, its strengths and weaknesses (Table 2).

Table 2. SWOT analysis of the implementation of a capsule hotel

	Strengths (S)	**Weaknesses (W)**
Internal environment	- higher comfort compared to a hostel; - availability of personal space; - lower cost compared to a separate room; - possibility of daily rent; - budget accommodation option; - easy maintenance of capsule rooms, quick cleaning and cleaning.	- the complexity of producing capsules; - difficulty of promoting advertising; - focused on a specific segment of consumers; - not suitable for people with a phobia of closed spaces.
	Opportunities (O)	**Threats (T)**
External environment	- passive business; - fast payback period; - uniqueness of the idea; - relatively small costs compared to other forms of hotel business.	- unsuccessful accommodation of the hotel leads to a decrease in demand; - strengthening of quarantine measures; - military situation in the country; - increase in taxes.

Source: author's own elaboration

So, during the SWOT analysis, it was found that the implementation of the capsule hotel has more positive aspects. Of course, it is risky to open this kind of hotel during the military situation in the country, but this idea should be, as it is a good step to improve the tourism and hotel business, especially in the direction of wellness.

In order to determine the consumer segment, a survey was conducted in Google Form (https://docs.google.com/forms/d/1ZBQnlWsY_PaWHU_CY7rMdf_pyUojNjWohFiNa7DxaA8/edit?usp=sharing), in order to create a better marketing strategy for the implementation of the capsule hotel. 23 respondents participated in the survey, the answers in some questions are very similar, and in some they differ from each other altogether. Therefore, the analysis of respondents' answers is presented below.

Analyzing the answer to the question "What do you miss in accommodation facilities?", the respondents had their own interesting and diverse answers. Thanks to this question, hoteliers can improve the operation of the hotel.

Examples of answers to this question:

- Bonuses or services included in the price of accommodation;
- Sometimes there is not enough food directly in the accommodation facility;
- Sometimes a small workplace;
- Privacy, in some case – personal hygiene products;
- A nice and clear city guide as a gift, etc.

As a result of the survey, the age structure of the respondents and the type of tourism chosen by consumers were compared (Fig. 4). Almost all respondents up to 18 and older chose the cultural and educational type of tourism. Respondents from 41 to 50 and 3 people under 30 choose beach tourism. And only one person chose some other type of recreation. It can be concluded that most tourists travel in order to gain knowledge and learn the culture of other countries or regions.

Fig. 4. Respondents' answers to the question
"What kind of tourism do you like?" depending on age
Source: author's own research

The next questions for comparison were questions about the profession and which accommodation facility a person with the appropriate status would choose (Fig. 5). The following results were obtained:

- 9 respondents answered that it does not matter where to stay (worker – 2; student – 5; schoolboy – 1; unemployed – 1);
- 6 respondents answered that they would choose a hotel (worker – 3; student – 2; unemployed – 1);
- 5 survey participants prefer to rent housing (worker – 3; student – 1; unemployed – 1);
- 1 person-student said that he would most likely choose a hostel;
- 2 respondents cannot answer this question (schoolboy – 1; other – 1).

Fig. 5. Respondents' answers to the question
"Where do you prefer to stay?" depending on the profession
Source: author's own research

Summarizing, it is highlighted that in most cases people don't care where to stay. Employees prefer to rent housing and some choose the "classic" – to stay in a hotel.

The survey also raised the question of what is the most important thing in a hotel (Fig. 6) and room (Fig. 7) for a tourist.

If we are talking about a hotel, the price, staff qualifications, interior service quality, and location are used to compare the degree of significance.

1) In the first place for the respondents is the price;
2) The second place is taken by the location;
3) The third place is taken by the quality of service;
4) On the fourth – personnel qualification;

5) The fifth place remains for the interior.

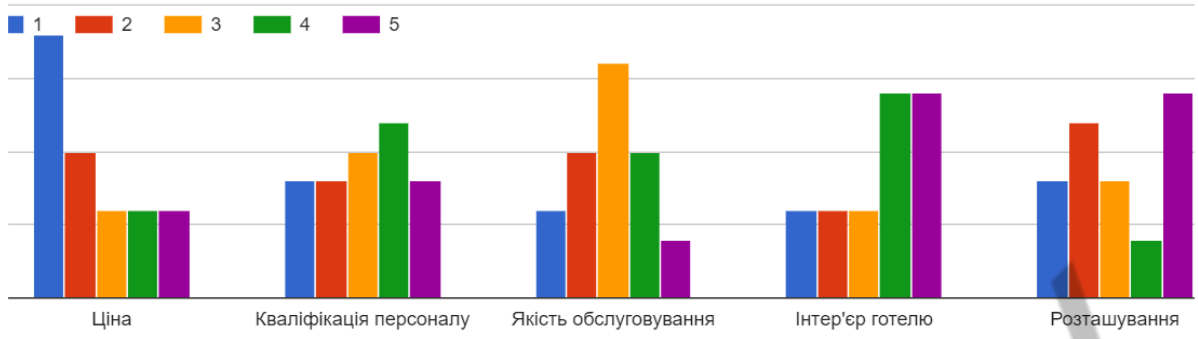

Fig. 6. Respondents' answers to the question
"Estimate the value of the components of the hotel"
Source: author's own research

Therefore, the majority of consumers choose the price-to-quality ratio.

Analyzing respondents' answers to the question "Estimate the criteria for staying in the room", criteria such as silence in the room, bed, interior, view from the window, and availability of a safe were used for comparison.

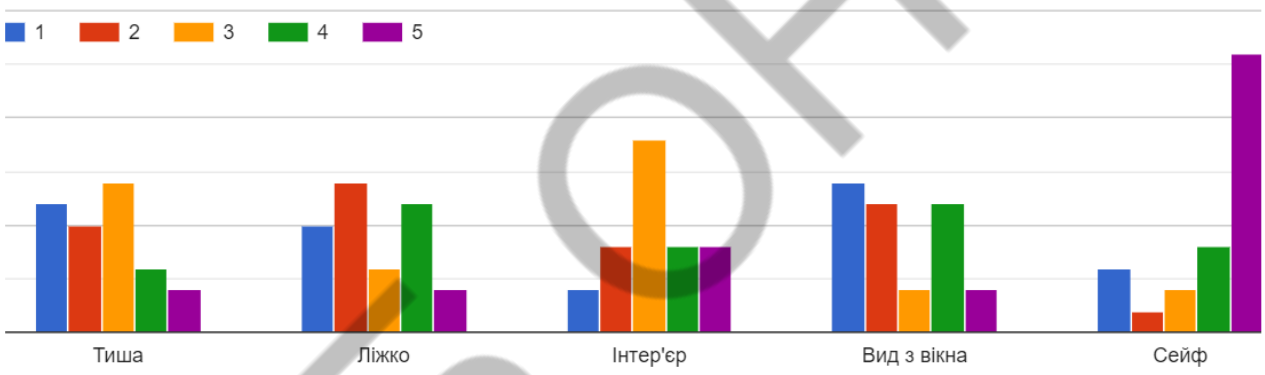

Fig. 7. Respondents' answers to the question
"Estimate the criteria for staying in the room"
Source: author's own research

The following results were obtained:

1) The view from the window takes first place by a large margin;

2) The second place for most is the bed;

3) The third place was divided between interior and silence;

4) For many respondents, the safe is not an important part of the room, therefore it takes the last place.

Based on the results of this survey, hoteliers should take into account the location of the hotel and the attractive view from the window that the consumer will have. It is certain that the location is a criterion that should be given more attention, the popularity of the accommodation depends on it.

It can be concluded that the ergonomics of the capsule hotel allows it to be built, even indoors, in the center or in a part of the railway station or airport, with a small area, which will significantly reduce searches and energy consumption when implementing the hotel's business plan.

Like every hotel enterprise, a capsule hotel needs equipment, decor and material and technical base. Therefore, in the table 3, the initial investments required for the initial stage of realization of the capsule hotel are presented.

Table 3. Start-up investments for the realization of a capsule hotel

No	Cost elements	Cost, UAH
1	Capsules	660 000
2	Materials for the preparation of the hotel premises	150 000
3	TV and other electronics	33 000
4	Furniture	45 000
5	Office equipment	22 000
6	Security system	15 000
7	Plumbing	50 000
8	Capsule decor	5 000
9	Other	20 000
Total costs		1 000 000

Source: author's own research

According to the table 3 initial investments amounted to UAH 1,000,000 (a price difference of 10-15% may be observed, which is connected with the choice of equipment of different quality, as well as taking into account the exchange rate of foreign currency).

In the operation of a hotel enterprise, there are always costs, such as the payment of wages, the purchase of additional equipment, and the payment of rent. And in order to understand the payback period of the business plan, the hotelier needs to sum up all these costs and have an idea of how much of the income will fall on these costs (Table 4).

Table 4. Expenses for maintaining a capsule hotel per month

Cost elements	Cost, UAH
Conditional fixed costs	114 000
1. Wages for hotel employees	62 000
2. Advertising	3 000
3. Internet, Wi-Fi	1 000
4. Payment for services of outsourcing firms	8 000
5. Renting the premises	40 000
Conditional variable costs	30 000
1. Premium payments	3 000
2. Costs of materials (linen, hygiene products, stationery, etc.)	7 000
3. Payment for utility services	10 000
4. Other expenses	10 000
Total costs	144 000

Source: author's own research

So, in the table 4, the monthly expenses of the capsule hotel are indicated. Of course, they can change depending on the needs. But the table shows the line "other expenses", which makes it possible to save and redistribute funds for emergencies.

To understand how the launch of the capsule hotel will be implemented, a calendar plan-schedule has been developed, which gives us the details of the steps and their execution time, and also shows the costs at each of the stages (Table 5).

Table 5. Calendar plan-schedule of the implementation of the business project "Capsule Hotel Shangri-La"

No	Content of the stage	Implementation period, week number from the start of work												The cost of the stage, UAH
		1	2	3	4	5	6	7	8	9	10	11	12	
1	Business registration													3 000
2	Market analysis													0
3	Search for partners													0
4	Search for premises													2 000
5	Repair work in the premises													1 000 000
6	Purchase and installation of equipment													
7	Purchase of household appliances, electronics													
8	Recruitment and training of hotel staff													0
9	Marketing activities to promote the hotel													3 000
10	Opening of a capsule hotel													3 000
Total costs														1 011 000

Source: author's own research

According to the schedule, the process of opening the hotel will take 12 weeks (approximately 3 months). It involves the stages of analysis and search, as well as the stages of direct performance of work.

Let's calculate the revenue of the capsule hotel as follows: 50 (number of capsules) x 400 (cost per night (UAH), cell rental rate) x 0.45 (lowest indicator in the range of occupancy of the hotel) x 30 (days per month). Thus, with a hotel occupancy of 45-50% and a cost of UAH 400 per night, the revenue will be about UAH 270,000 per month. The annual revenue of the business will be UAH 3,240,000. If the costs are deducted, a net profit of UAH 501,000 per year will be obtained.

As can be seen from the calculations, the payback period of this business is quite short and will be at least 5 months, taking into account the pandemic situation and the military situation in the country. In practice, such successful projects have a payback period of 6-12 months. But there are also large projects that have a payback period of up to 2 years.

It should also be noted that the calculations take into account the use of own (non-borrowed) funds. The efficiency of this business will make it possible to use loan resources (bank loan). At the same time, of course, profitability will decrease, and the payback period of the business will increase.

V. CONCLUSIONS

So, a capsule hotel is a promising and profitable business in the hotel industry of Ukraine. Various technological advances, use of artificial intelligence in capsule hotels will contribute to the growth of the market.

Taking into account modern business conditions, reality forces to invest in well-thought-out projects that require less expenses and that will bring the greatest possible profit. Especially if such a business (capsule hotel) will not occupy a large area. Even if we consider this issue from the perspective of demography and ergonomic use of the territory, location, then such a business as a capsule hotel meets all the above-mentioned requirements. It does not need a lot of space and can accommodate most people, while large hotels have 60 rooms, capsule hotels can have 100 capsules and it will take up much less space.

It is worth noting that recently, experienced tourists pay less attention to the luxury, grandeur and stardom of the hotel, and more to comfort and price. Travelers are increasingly removing excess from the trip. BB – Bed and Breakfast – everything you need to have in an accommodation facility. And if such a hotel also provides privacy, compared to another cheap alternative – a hostel, then capsule hotels are an ideal option for temporary accommodation.

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DEVELOPMENT OF DIABETIC SWEET DISHES FOR HOTEL BREAKFAST MENUS

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Abstract. *The scientific work actualizes the issue of expansion and improvement of dietary dishes for hotel breakfast menus. Today, diabetes is the most widespread disease in the world, which has a good relationship with nutrition. However, there is practically no assortment of desserts for people with diabetes in the hotel and restaurant industry.*

The paper analyzes the demand for sweet dishes during breakfast in hotel restaurants and substantiates their choice for improvement. The main causes of the disease, the peculiarities of nutrition, a brief description of sugar substitutes and sweeteners are given.

On the basis of the conducted research, the most optimal dosages of sugar substitutes and sweeteners were determined, and the change in the energy value of sweet dishes due to the removal of easily digestible carbohydrates was calculated. As a result, the assortment of diabetic dishes has been expanded, which fully satisfy the gastronomic needs of people suffering from diabetes without the need to give up sweet dishes.

Keywords: *diabetes, sugar substitutes, sweeteners, easily digestible carbohydrates, diabetic nutrition, hotel industry.*

I. INTRODUCTION

Food is an integral part of the organization of accommodation and accommodation in hospitality enterprises. Yes, almost every traveler, staying in a hotel, motel or sanatorium, visits the restaurants located on their territory. However, not every guest can satisfy their gastronomic preferences and needs regarding physiological norms of nutrition and health features.

It is known that today a significant number of the population has problems with the assimilation and intolerance of certain nutrients. The issue of consumption of sugar and sugar-containing products is especially acute for people suffering from diabetes. This disease occupies one of the leading places in the structure of endocrine pathology and belongs to one of the main socio-medical and research problems, both in Ukraine and throughout the world. Every year, the number of patients is increasing, which indicates a global epidemic with complex diabetic complications that can lead to a shortening of life.

Scientists have proven that excessive consumption of sugar and other easily digestible carbohydrates can lead to cardiovascular and endocrine diseases, increased cholesterol and blood sugar levels, excess weight, and many other problems. Excessive consumption of sucrose causes resistance to insulin, which is produced by the pancreas, as a result of which the body cannot function fully. Based on this, there are

recommendations for the complete exclusion of sugar from the diet of people or its replacement with sugar substitutes and sweeteners.

II. LITERATURE ANALYSIS

2.1. The current state of the development of diabetes and the peculiarities of nutrition during the disease

Diabetes mellitus is a fairly common chronic disease, characterized by an increase in the level of glucose in the blood due to a violation of insulin production or insensitivity to it, that is, there is an incomplete conversion of glucose into energy [1].

There are six types of diabetes in total, but type I and type II diabetes are most common in clinical practice.

Type I diabetes begins in childhood or adolescence. The pancreas produces insufficient insulin or it is completely absent. Changes occur in the cells of the pancreas that produce insulin, caused by genetic mechanisms, environmental factors and viral infections that the child or teenager has had.

Type II diabetes is observed in almost 90-95% of patients, it is diagnosed in adults over 40 years old. The pancreas produces enough insulin, but the body's cells do not respond properly because they are resistant to insulin.

According to general statistics, about 3% of the population suffers from this disease, and the number of patients doubles every 10-15 years in all countries of the world. Diabetes mellitus ranks third among diseases, which is the most frequent cause of disability and mortality of patients [2].

The issue of dietary nutrition for people suffering from diabetes is dealt with by leading scientists of Ukraine from both the food industry and medicine: A.M. Dorokhovych, V.V. Dorokhovych, P. M. Bodnar, M. F. Grynenko, V. G.Baranova, M. V. Stepashko, V. K. Dobrovolskyi and others.

Most of the developments related to dietary nutrition for diabetics are aimed at industrially produced products (biscuits, candies, halva, cakes, etc.). If we analyze the sweet dishes offered by restaurants, we can state that their range needs to be expanded and improved.

There are only a few sanatoriums for diabetes patients operating in Ukraine, and all of them are located on the territory of Zakarpattia and Prykarpattia. However, in other regions of Ukraine, people are also sick and should have the opportunity to stay in hotels where it would be possible to get a meal service taking into account the features of diabetic nutrition.

Features of nutrition in diabetes are caused by the need to reduce energy value by reducing the consumption of animal fats and easily digestible carbohydrates. As for the content of proteins in the diet, they are within the norm of the daily amount of consumption, or may slightly exceed this limit. It is necessary to increase the amount of consumed products containing lipotropic substances, dietary fibers and vitamins. Such products include: sour milk cheese, fish and seafood, fruits and vegetables, whole grain cereals and bread made from coarsely ground flour. It is recommended to completely exclude sugar, replacing it with natural sugar substitutes and sweeteners [3].

When suffering from diabetes, food should be consumed in small portions, at the same time, at least 5-6 times a day. It is also necessary to divide the daily food intake into 3 main meals and 2-3 additional meals.This helps maintain body weight within normal limits and prevents sharp fluctuations in the level of glucose in the blood after a meal.

With diabetes, it is necessary to follow diet No. 9. At the same time, it is strictly forbidden to eat food that simultaneously contains a large amount of fats and carbohydrates (chocolate, confectionery, creamy ice cream). Recommended chemical composition and caloric content of the diet: proteins - 100 g, fats - 80 g, carbohydrates - 300 g. Caloric content of the diet: 2300 kcal/day. Diet: 5-6 times a day.

2.2. Sugar substitutes and sweeteners.

The group of sugar substitutes and sweeteners includes non-sugar substances that give dishes a sweet taste.

The difference between sugar substitutes and sweeteners is that sugar substitutes are substances with a sweet taste, which are used in relatively large quantities and can participate in the formation of the product structure (fructose, sorbitol, xylitol, maltitol, lac thiol, etc.), and sweeteners are substances non-carbohydrate nature, which are used in very small quantities to give the product a sweet taste and have no energy value [4].

Sweeteners are divided into artificial, obtained as a result of chemical reactions, and natural, produced from vegetable raw materials. The second category of sweeteners is artificial, developed in the laboratory through various chemical reactions.

Synthetic sweeteners can often be found in food: saccharin, sucralose, cyclamate and aspartame (E951), as well as sorbitol (E420), malit (E965), acesulfame K (E950), thaumatin (E957), neohesperidin (E959), isomalt (E953) and others.

However, the most popular natural sweeteners from plant raw materials are stevia, thaumatin, and glycyrrhizin. They are used in very small quantities, as their sweetness is 100-3000 times higher than that of ordinary sugar.

We chose fructose, stevia and erythritol from a wide range of sugar substitutes.

Fructose is a sugar component found in fruits, vegetables and honey. Fructose tastes 1.5 times sweeter than sugar and is also high in calories.It is produced in the form of a white powder and has good soluble properties in water. Fructose takes a long time to be absorbed, so it does not cause sudden spikes in insulin in the blood and is allowed to be used in diabetes in a small amount, about 45 g per day. [5]

Stevia is obtained from the herbaceous culture of the same name, which is called "honey grass". The permissible dose per day is up to 4 mg per kilogram of human weight. Among the useful properties of stevia is the presence of vitamins of PP, B and C groups in its extract. These groups of vitamins are responsible for cell regeneration, metabolism, and strengthening the immune system. [5]

Erytriol is crystalline in nature, it has no smell, and the caloric content of the substance is negligible. The level of sweetness is 70% compared to the taste of sugar, so it is not harmful when consumed even in larger quantities than sucrose [5].

To replace sugar, the following were chosen: sugar substitute - fructose "AKURA"; sweetener - sweet stevia "GREEN LEAF"; sweetener - erythritol "GREEN LEAF". The characteristics of the selected sugar substitutes and sweeteners are given in Table 1.

Table 1 - Characteristics of sugar substitutes and sweeteners

The name of the sugar substitute	Advantages	Disadvantages	Energy value, kcal	Sweetness level
Fructose «AKURA»	➢ Has a less aggressive effect on tooth enamel compared to sucrose; ➢ Is responsible for the stability of glucose in the blood; ➢ Has a tonic effect.	Active consumption of fructose leads to an increased load on the liver	368	1,6…1,8:1
Sweet stevia «GREEN LEAF»	➢ No calories; ➢ Normalizes blood pressure; ➢ Contains antioxidants; ➢ Removes toxins; ➢ Lowers the level of harmful cholesterol; ➢ Contains potassium; ➢ Rich in vitamins of pp, b and c groups.	Specific taste and smell	0	1:1
Erythritol «GREEN LEAF»	➢ No calories; ➢ Lack of smell; ➢ The appearance does not differ from sugar; ➢ No harm in moderation.	Missing	0	0,6…0,8:1

2.3. Classification and characteristics of sweet dishes

Sweet dishes are served at the end of lunch or dinner for dessert, so they are also called dessert dishes, and they are also included in the breakfast menu.

According to the composition and method of preparation, sweet dishes are classified into natural fruits and berries, compotes, sweet dishes with substances capable of forming jelly; hot sweet dishes.

According to the serving temperature, all dishes of this group are divided into hot (55°C) and cold (10-14°C). However, this division is conditional, since many dishes are served both hot and cold.

The nutritional value of sweet dishes depends on the nutritional value of the products included in their composition. Fresh, dried and canned fruits and berries, fruit and berry syrups, juices, extracts containing various minerals, vitamins, carbohydrates, essential oils, food acids and dyes are used to prepare sweet dishes. Some sweet dishes include dairy products - milk, cream, sour cream, butter, cheese, eggs, cereals, rich in proteins and fats and high in calories. Aromatic and flavoring substances of sweet dishes are vanilla, cinnamon, citrus peel, citric acid, coffee, cocoa, wine, raisins, nuts, etc.

Dishes have a sweet taste due to their content of various sugars: sucrose, glucose, fructose. The average adult's need for sugars should not exceed 100 g per day, and their excessive consumption leads to the deposition of fat, an increase in the level of cholesterol in the blood and other negative phenomena. Fructose, glucose and maltose have a lower ability to accumulate fats in the body, so sweet dishes, which include

milk, fresh and canned fruits and berries, and fruit and berry juices, are considered the most valuable.

Sweet dishes prepared from fresh fruits and berries increase the secretion of digestive juices, which at the end of the meal weakens somewhat, and promotes better digestion.

III. OBJECT, SUBJECT AND METHODS OF RESEARCH

The object of research is the technology of sweet diabetic dishes.

The subject of the study is "AKURA" fructose, "GREEN LEAF" sweet stevia, "GREEN LEAF" erythritol, sugar, cheesecakes, pancakes and casseroles.

Research methods are statistical, analytical, organoleptic, performed according to standard methods with the use of modern mathematical tools for processing the obtained results.

IV. WORK RESULTS

4.1. Analysis of the demand for consumption of sweet dishes during breakfasts in hotels

After conducting a survey of guests at the hotels "Premier Palace Hotel Kyiv" and "Hilton Kyiv", it was found that among the dishes offered during breakfast, the most popular among consumers are: cheesecakes, pancakes and casseroles (Table 2, Fig. 1 and Fig. 2). Based on the results of the survey, three dishes most commonly used during breakfasts in hotels were chosen to replace sugar with a natural sweetener.

At the "Premier Palace Hotel Kyiv" breakfast is attended by approximately 103 guests daily, among them:

- Cheesecakes – 25;
- Pancakes with sour milk cheese - 13;
- Casserole - 20;
- Milk porridge - 5;
- Fresh fruits and berries – 17;
- Pancakes – 23.

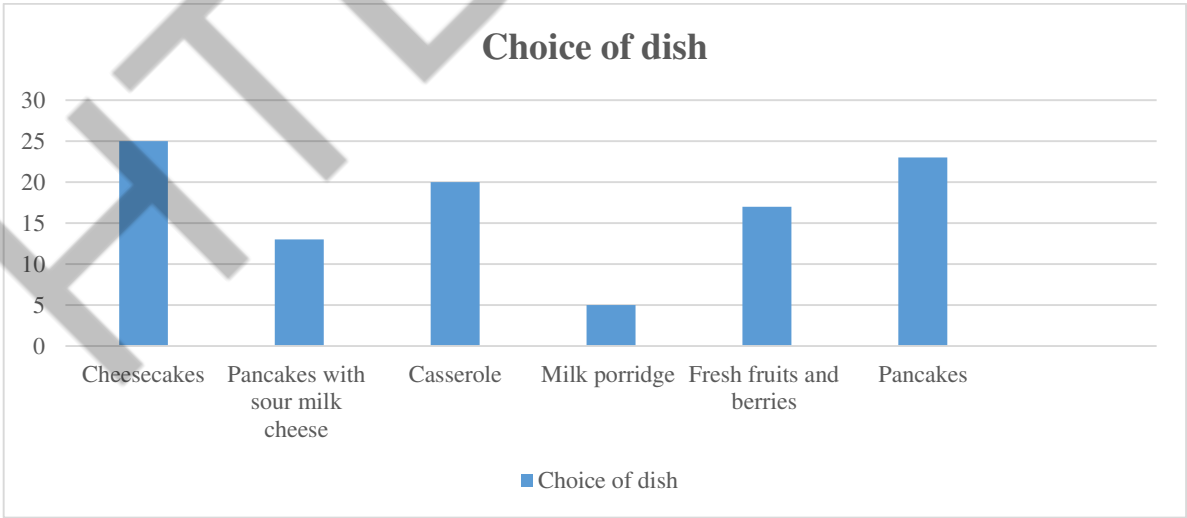

Fig. 1 – Results of a survey of guests at the Premier Palace Hotel Kyiv

In turn, at the Hilton Kyiv hotel, with the same assortment of dishes served at breakfast and an approximate number of 252 guests, the choice of dishes was as follows:

- Cheesecakes – 74;
- Pancakes with sour milk cheese - 20;
- Casserole - 48;
- Milk porridge - 18;
- Fresh fruits and berries – 33;
- Pancakes - 59.

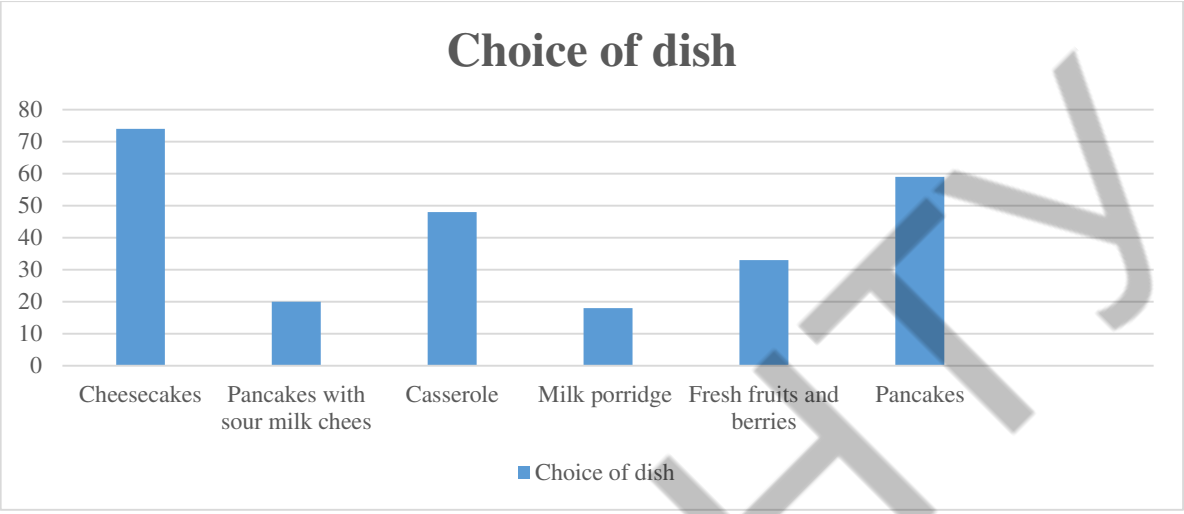

Fig. 2 – Results of a survey of guests at the Hilton Kyiv hotel

Table 2 – Desires of surveyed guests of hotel services

The name of the dish	Respondents' choice of meals in hotels	
	«Premier Palace Hotel Kyiv»	«Hilton Kyiv»
Cheesecakes	25	74
Pancakes with sour milk cheese	13	20
Casserole	20	48
Milk porridge	5	18
Fresh fruits and berries	17	33
Pancakes	23	59

Based on the received data, it was cheesecakes, casseroles and pancakes that were chosen for technology improvement.

4.2. Development of the technology of sweet dishes with sugar substitutes

For the preparation of diabetic dishes, we took into account previous studies and selected the most widely used recipes, namely: No. 463 "Sour-milk cheese curds", No. 469 "Sour-milk cheese casserole" [6] and pancakes [7]. In traditional recipes, sugar was replaced with a sugar substitute or sweetener, taking into account the level of sweetness.

To replace 100 g of sugar, it is necessary to take: fructose - 60...80 g, sweet stevia - 100 g, erythritol - 120...140 g (Table 1). Based on this, the following dosages were taken for cheesecakes and casseroles: stevia licorice - 10 g, 15 g and 20 g; erythritol - 18 g, 19.5 g and 21 g; fructose - 9 g, 10.5 g and 12 g. For pancakes, we took: sweet stevia - 20 g, 30 g and 40 g; erythritol - 36 g, 39 g and 42 g; fructose - 18 g, 21 g and 24 g.

On the basis of the conducted research, technological cards were developed for dishes prepared according to classic recipes - as a control sample, and with three different dosages of sugar substitutes and sweeteners in order to establish the most optimal option. Optimum dosages of sugar substitutes were determined among the twelve processed recipes, technological cards for new dishes were developed, their energy value and glycemic index were calculated.

Table 3 - Technological map for the dish "Cheesecakes with sugar substitutes"

№ s/p	The name of the raw material	The rate of content in a finished dish or product (g)						Technological requirements for the quality of raw materials
		With stevia		With erythritol		With fructose		
		gross	net	gross	net	gross	net	
1	Sour milk cheese	135	133	135	133	135	133	DSTU 4554:2006
2	Sweet stevia	15	15	-	-	-	-	TU U 10.8-4316955-002:2020
3	Erythritol			21	21	-	-	GOST R 53904-2010
4	Fructose	-	-	-	-	9	9	TU U 10.8-38983027-009:2019
5	Chicken eggs	1/8 piece	5	1/8 piece	5	1/8 piece	5	DSTU 5028:2008
6	Wheat flour	20	20	20	20	20	20	DSTU 46.004-99
The weight of the semi-finished product		-	170	-	170	-	170	
7	Sunflower oil	5	5	5	15	5	15	DSTU 4492:2005
The mass of the finished dish		-	150	-	150	-	150	

Technological parameters

№ p.p	Types of losses	Normative value, %	Actual value, %
1	Mechanical: Sour milk cheese	1	1
2	Thermal: Sour milk cheese	12	10

Food preparation technology

2/3 of the sifted flour, eggs, sugar, and salt are added to the grated cheese. You can add vanillin 0.02 g per portion, having previously dissolved it in hot water. Mix the mass well, give it the shape of a bar 5-6 cm thick, cut it crosswise, dust it in flour, give it the shape of round flattened balls 1.5 cm thick, fry it on both sides, then put it in the cabinet for frying for 5-7 minutes and bring to readiness.

Submission rules

Cheesecakes are released on a heated dessert plate, 3 pieces each. per portion with sour cream or jam, or sour cream with sugar, with milk or sour cream, or sweet sauce. The serving temperature is 65°C.

Table 4 - Technological map for the dish "Sour-milk cheese casserole with sugar substitutes"

№ s/p	The name of the raw material	The rate of content in a finished dish or product (g)						Technological requirements for the quality of raw materials
		With stevia		With erythritol		With fructose		
		gross	net	gross	net	gross	net	
1	Sour milk cheese	136	135	136	135	136	135	DSTU 4554:2006
2	Sweet stevia	15	15	-	-	-	-	TU U 10.8-4316955-002:2020
3	Erythritol	-	-	21	21	-	-	GOST R 53904-2010
4	Fructose	-	-	-	-	9	9	TU U 10.8-38983027-009:2019
5	Chicken eggs	1/8 piece	5	1/8 piece	5	1/8 piece	5	DSTU 5028:2008
6	Wheat flour	12	12	12	12	12	12	DSTU 46.004-99
7	Sunflower oil	5	5	5	5	5	5	DSTU 4492:2005
8	Breadcrumbs	5	5	5	5	5	5	DSTU 8708:2017
9	Sour cream 10%	5	5	5	5	5	5	DSTU 4418:2005
	The mass of the finished dish	-	150	-	150	-	150	

Technological parameters

№ p.p	Types of losses	Normative value, %	Actual value, %
1	Mechanical: Sour milk cheese	1	1
2	Thermal: Sour milk cheese	12	10

Food preparation technology

Grated cheese is mixed with flour, eggs, sugar and salt. The prepared mass is laid out in a layer of 3-4 cm on a baking sheet or form greased with oil and sprinkled with breadcrumbs. The surface of the mass is leveled, smeared with sour cream, baked in the oven for 20-30 minutes until a ruddy crust forms on the surface.

Submission rules

Before serving, the casserole is cut into square, rectangular or triangular portions. The serving temperature is 65oC.

Table 5 - Technological map for the dish "Pancakes with sugar substitutes"

№ s/p	The name of the raw material	The rate of content in a finished dish or product (g)						Technological requirements for the quality of raw materials
		With stevia		With erythritol		With fructose		
		gross	net	gross	net	gross	net	
1	Sweet stevia	40	40	-	-	-	-	TU U 10.8-4316955-002:2020
2	Erythritol	-	-	42	42	-	-	DSTU 5028:2008
3	Fructose	-	-	-	-	24	24	DSTU 46.004-99
4	Chicken eggs	1 piece	40	1 piece	40	1 piece	40	DSTU 2900:2006
5	Wheat flour	210	210	210	210	210	210	DSTU 2661:2010
6	Baking powder	10	10	10	10	10	10	DSTU 4339:2005
7	Milk	200	200	200	200	200	200	TU U 10.8-4316955-002:2020
8	Butter	25	25	25	25	25	25	DSTU 5028:2008
The mass of the finished dish		-	200	-	200	-	200	

Food preparation technology

Prepared eggs are mixed with sugar and salt, beaten thoroughly. Add milk, soft butter and mix again. Gradually add flour and baking powder, mixing the dough. Spoon the dough onto a dry heated pan and fry on both sides.

Submission rules

8 pancakes are released on a heated dessert plate. per portion The serving temperature is 12...14oC or 55...65oC.

During the preparation of dishes and conducting their organoleptic evaluation, the most optimal dosages of sugar substitutes were determined. The results are shown in Table 6.

Table 6 – Optimal dosage of sugar substitutes and sweeteners in the composition of sweet dishes

Dish	The name of the sugar substitute or sweetener		
	Fructose «AKURA»	Sweet stevia «GREEN LEAF»	Erythritol «GREEN LEAF»
Cheesecakes	9	15	21
Casserole	10,5	15	18
Pancakes	24	40	42

4.3. Evaluation of indicators of quality, nutritional and energy value, glycemic index of dietary sweet dishes

To objectively assess the organoleptic indicators of the quality of ready meals, tastings were conducted, based on the results of which quality profilographs were constructed (Figs. 3-6).

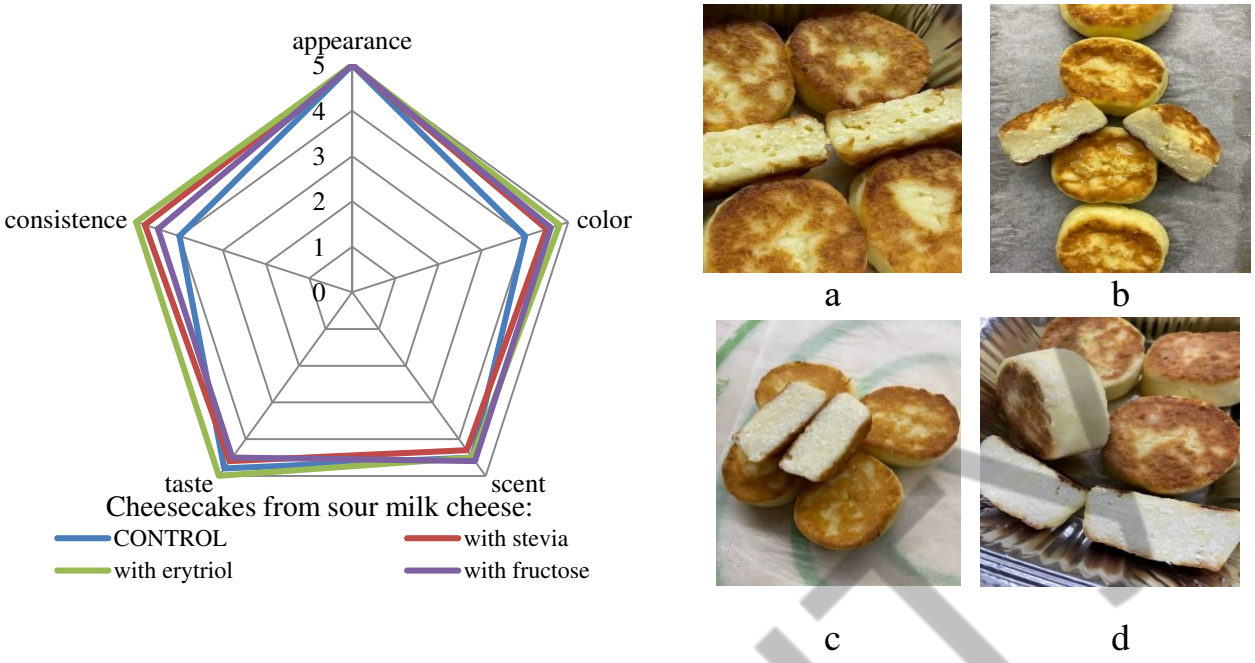

Fig. 3 – Quality profile and appearance of sour-milk cheese curds: a – control, b – with stevia, c – with erythritol, d – with fructose

Having analyzed and compared the organoleptic indicators of the quality of sour-milk cheese curds, it can be stated that all experimental samples practically do not differ in taste, appearance, taste, smell and consistency.

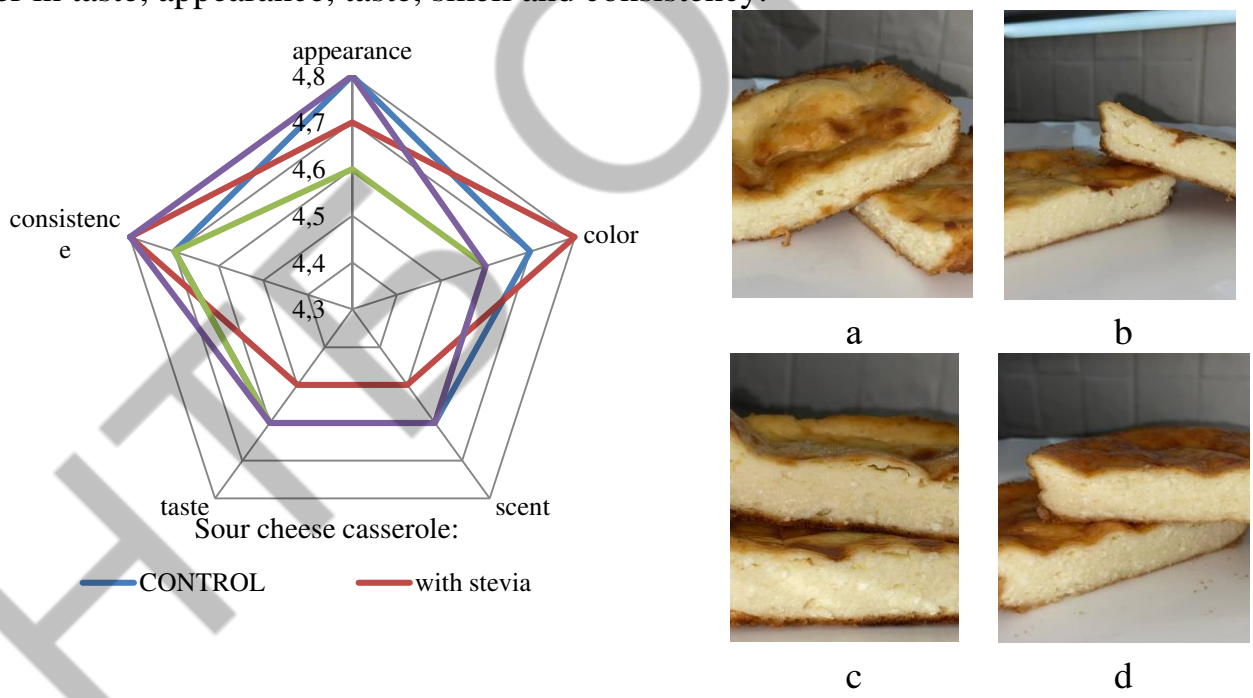

Fig. 4 – Quality profile and appearance of sour-milk cheese casseroles: a – control, b – with stevia, c – with erythritol, d – with fructose

Based on the tasting evaluation of the casseroles, it was established that all the experimental samples received high scores, however, the sample with stevia received a slightly lower number of points in terms of taste and smell, which is due to its specific taste.

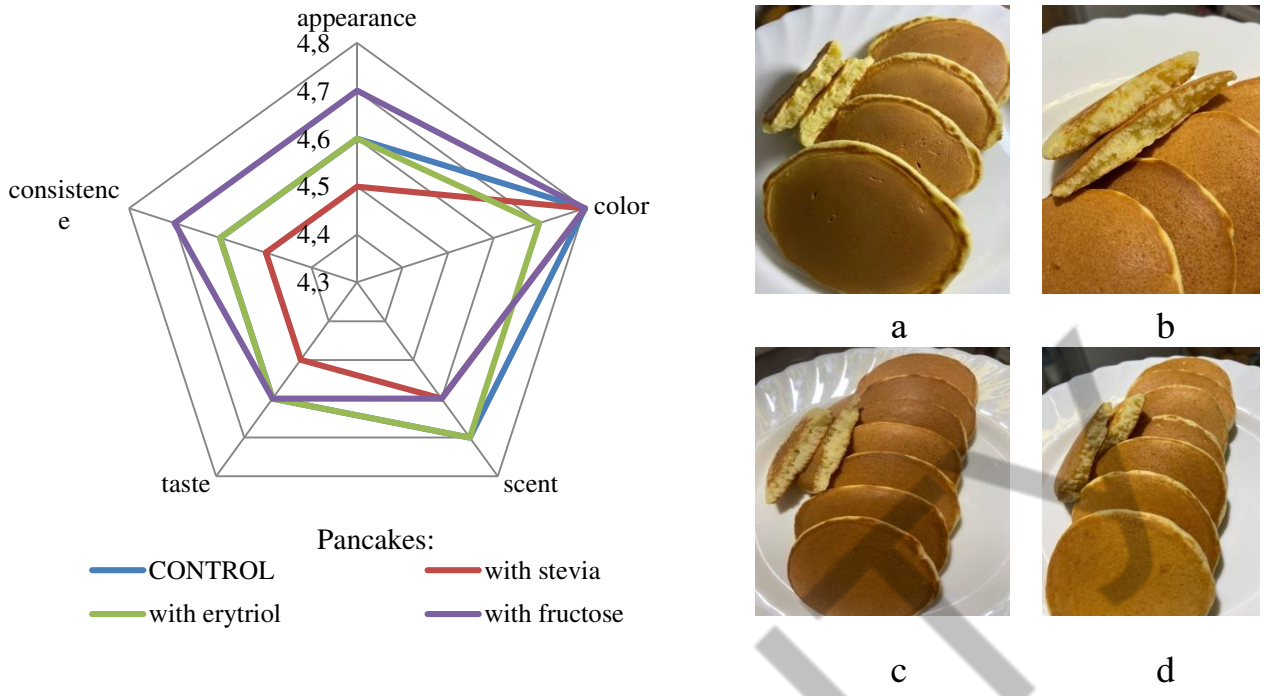

Fig. 5 – Quality profile and appearance of pancakes: a – control, b – with stevia, c – with erythritol, d – with fructose

According to the results of the tasting evaluation, the pancakes received positive characteristics. Pancakes with fructose had the best total points, the lowest – with stevia, due to its taste characteristics.

The energy value of the developed dishes was calculated and compared with the classical recipe. As a result, by removing fast carbohydrates from dishes by replacing sugar, the energy value of dishes with stevia and erythritol is reduced by 18%, and with fructose by 6% (Table 7-9).

Table 7 - Comparative characteristics of the energy value of cottage cheese

Kind of cheesecakes	Weight, g	Proteins, g	Fats, g	Carbohydrates, g	Energy value, kcal
Classic recipe$_1$	150	25,55	12,48	32,54	344,68
Cheesecakes with stevia$_2$	150	25,55	12,48	17,54	284,68
Cheesecakes with erythritol$_3$	150	25,55	12,48	17,54	284,68
Cheesecakes with fructose$_4$	150	25,55	12,48	26,36	319,96

EC_1=25.55*4+12.48*9+32.54*4=102.2+112.32+130.16=344.68 kcal (1442.14 kJ). Energy value per 100 g – 229.78 kcal (961.39 kJ), including: proteins – 17.1 g; fats - 8.32 g; carbohydrates - 21.6 g.

EC_2=25.55*4+12.48*9+17.54*4=284.68 kcal (1232.94 kJ). Energy value per 100 g – 189.7 kcal, including: 17.1 g; fats - 8.32 g; carbohydrates – 11.6 g.

EC_3=25.55*4+12.48*9+17.54*4=284.68 kcal (1232.94 kJ). Energy value per 100 g – 189.7 kcal, including: 17.1 g; fats - 8.32 g; carbohydrates – 11.6 g.

EC_4=25.55*4+12.48*9+26.36*4=319.96 kcal (1338.71 kJ). Energy value per 100 g – 213.3 kcal (892.44 kJ), including: 17.1 g; fats - 8.32 g; carbohydrates – 17.5 g/

Table 8 – Comparative characteristics of the energy value of casseroles

Kind of cheesecakes	Weight, g	Proteins, g	Fats, g	Carbohydrates, g	Energy value, kcal
Classic recipe$_1$	150	25,4	18,4	30,72	390,2
Casserole with stevia$_2$	150	25,4	18,4	15,72	330,08
Casserole with erythritol$_3$	150	25,4	18,4	15,72	330,08
Casserole with fructose$_4$	150	25,4	18,4	24,54	365,36

EC_1=25.4*4+18.4*9+30.72*4=101.6+165.6+123.0=390.2 kcal (1632.5 kJ). Energy value per 100 g – 260.1 kcal (1088.2 kJ), including: proteins – 16.9 g; fats - 12.2 g; carbohydrates - 20.48 g.

EC_2=25.4*4+18.4*9+15.72*4=101.6+165.6+62.88=330.08 kcal (1381.05 kJ). Energy value per 100 g – 220.05 kcal (920.68 kJ), including: proteins – 16.9 g; fats - 12.2 g; carbohydrates - 10.48 g.

EC_3=25.4*4+18.4*9+15.72*4=101.6+165.6+62.88=330.08 kcal (1381.05 kJ). Energy value per 100 g – 220.05 kcal (920.68 kJ), including: proteins – 16.9 g; fats - 12.2 g; carbohydrates - 10.48 g.

EC_4=25.4*4+18.4*9+24.54*4=101.6+165.6+98.16=365.36 kcal (1528.66 kJ). Energy value per 100 g – 243.57 kcal (1019.09 kJ), including: proteins – 16.9 g; fats - 12.2 g; carbohydrates - 16.36 g; of them sugars - 0.12 g.

Table 9 - Comparative characteristics of the energy value of pancakes

Kind of cheesecakes	Weight, g	Proteins, g	Fats, g	Carbohydrates, g	Energy value, kcal	Kind of cheesecakes
Classic recipe$_1$	200	31,95	22,34	197,88	42,26	1120,38
Pancakes with stevia$_2$	200	31,95	22,34	167,88	12,26	1000,38
Pancakes with erythritol$_3$	200	31,95	22,34	167,88	12,26	1000,38
Pancakes with fructose$_4$	200	31,95	22,34	185,52	12,26	1070,94

EC1=31.95*4+22.34*9+197.88*4=127.8+201.06+791.52=1120.38 kcal (4687.66 kJ). Energy value per 100 g – 560.19 kcal (2343.83 kJ), including: proteins – 15.97 g; fats – 11.17 g; carbohydrates - 98.94 g; of which sugars – 21.13 g.

EC2=31.95*4+22.34*9+167.88*4=127.8+201.06+671.52=1000.38kcal (4185.58kJ). Energy value per 100 g – 500.19 kcal (2092.79 kJ), including: proteins – 15.97 g; fats – 11.17 g; carbohydrates - 83.94 g; of them sugars – 6.13 g.

EC3=31.95*4+22.34*9+167.88*4=127.8+201.06+671.52=1000.38kcal (4185.58kJ). Energy value per 100 g – 500.19 kcal (2092.79 kJ), including: proteins – 15.97 g; fats – 11.17 g; carbohydrates - 83.94 g; of them sugars – 6.13 g.

EC4=31.95*4+22.34*9+185.52*4=127.8+201.06+742.08=1070.94kcal (4480.81kJ). Energy value per 100 g – 535.47 kcal (2240.4 kJ), including: proteins – 15.97 g; fats – 11.17 g; carbohydrates - 92.76 g; of them sugars – 6.13 g.

The glycemic index of the developed dishes was calculated.

Table 10 - Comparative characteristics of glycemic indicators

	Control sample, PG/unit	Replacement for fructose, PG/unit	Replacement for sweet stevia, PG/unit	Replacement for erythritol, PG/unit
Cheesecakes	25,58	18,4	16,6	16,6
Casserole	23,09	16,21	14,11	14,11
Pancakes	123,21	110,04	105,24	105,24

According to the obtained results, when the studied additives are added to the recipe of cheesecakes, there is a decrease in the glycemic index by 28% with fructose and by 35.2% with sweet stevia and erythritol. When the tested additives are added to the casserole recipe, there is a decrease in the glycemic index by 29.8% with fructose and by 38.9% with sweet stevia and erythritol. When the researched additives are added to the recipe of pancakes, there is a decrease in the glycemic index by 10.7% with fructose and by 14.6% with sweet stevia and erythritol.

V. CONCLUSIONS

Today, the population's diet is characterized by excessive consumption of high-calorie foods and easily digestible sugars, such as sucrose and glucose. However, modern technologies make it possible to adjust the composition of sweet dishes and thereby reduce, or completely remove, unnecessary fast carbohydrates. Such technologies are characterized by replacing sugar with sugar substitutes and sweeteners.

The hotel industry needs to expand the assortment of sweet dishes for the breakfast menu at hotels, especially in the direction of diabetic nutrition. By improving the nutritional composition of the selected sweet dishes, the main goal was achieved - the extraction of easily digestible carbohydrates, in the form of sucrose, which is not digested in diabetes. Due to this, the energy value of dishes was reduced by 18% taking into account the use of sweet stevia and erythritol, and by 6% taking into account the use of fructose. Thus, the proposed dishes can fully satisfy the gastronomic needs of people suffering from diabetes without limiting their consumption of dessert dishes.

Based on the results of the scientific work, the abstracts of the reports ("Expanding the range of dietary sweet dishes in the restaurants at hotels" were published in the collection of the results of the II international scientific and practical multidisciplinary conference "Healthy nutrition from childhood to longevity: state and prospects, Kyiv, NUHT, 2022) r."), an article in a professional publication (A.V. Romanyuk, O.S. Pushka, T.A. Silchuk. Development of dietary dishes for hotel breakfast menus. Economy and society. 2022. No. 44. URL: https:/ /economyandsociety.in.ua/index.php/journal/article/view/1891 DOI: 10.32782/2524-0072/2022-44-108).

The results of the work have been implemented in the Lviv Chocolate Workshop restaurant, Kyiv (Appendix A).

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(Appendix A).

Затверджую

Директор ТОВ «КРОНАМІ»

_____ Собін О.В.

«13» січня 2023 р.

Акт впровадження

результатів наукового дослідження **Романюк Ангеліни** на тему:

«Організація харчування в закладах ресторанного господарства при готелях для людей, хворих на цукровий діабет»

Результати наукової студентської роботи прийнято до впровадження у заклад ресторанного господарства, зокрема:

- Враховано аналіз споживання десертів у закладах ресторанного господарства при готелях;
- Для приготування солодких став використано запропоновані цукрозамінники та підсолоджувачі;
- При складанні меню закладу додано нові страви здорового харчування.

DEVELOPMENT OF A RESTAURANT PRODUCT BASED ON THE CONCEPT OF A LOCAL RESTAURANT WITH CRAFT WINES OF UKRAINE

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Abstract. *Raising the prestige of Ukrainian craft wines and improving the culture of their consumption in Ukraine is an important task today. One of the most effective ways to introduce craft wines to consumers is to sell them in specialized wine shops, present them at exhibitions, participate in wine competitions, and taste them in conceptual wine restaurants. Given the growing demand for local craft products, especially wines, it was decided to develop a restaurant product that would combine the idea of popularizing Ukrainian craft wines with Ukrainian and European cuisine.*

Keywords: *restaurant product, local restaurant, conceptual wine restaurant, Ukrainian craft wines, Ukrainian and European cuisine.*

I. INTRODUCTION

The relevance of the study is due to the fact that the craft wine market has been constantly developing recently, as evidenced by the increasing number of family wineries and enterprises in different regions of Ukraine. The trend towards the consumption of craft products is well monitored through the implementation of such a project as "By the Roads of Wine and Taste of Ukrainian Bessarabia", whose tourist routes include visits to craft wineries in Odesa region.

Despite the growing interest in Ukrainian craft wines, there are still few restaurants in a major tourist city like Odesa that can offer foreign and domestic tourists a full list of Ukrainian craft wines, as well as dishes made from local products that will successfully combine with each other.

The purpose of the research is to substantiate a restaurant product based on the concept of a local restaurant of Ukrainian craft wines. The introduction of such a product will help popularize Ukrainian craft wines and demonstrate the potential of Ukrainian winemaking for foreign and domestic tourists.

II. LITERATURE ANALYSIS

Despite the very difficult times associated with the pandemic and the hostilities in Ukraine, the local restaurant business has not stopped developing. The following trends in the restaurant business were observed in 2020-2022 demand for restaurants with stylish and modern interiors and affordable prices; demand for restaurants serving Italian, Japanese, Ukrainian, Thai, vegetarian, and pan-Asian cuisines; demand for restaurants with banquet facilities demand for cafes with interesting sweets and delicious drinks; growing culture of coffee consumption; emergence of new formats - yogurt shops, mobile coffee shops, eco-friendly establishments, smoothie bars, cafe-cooking; popularity of art and themed establishments; demand for children's cafes with an

entertainment area; demand for fast food; demand for delivery services with their own catering facilities; demand for American-style establishments; fewer universal restaurants and more highly specialized establishments where favorite dishes are deliciously prepared (burger joints, pizzerias, cafes); demand for craft drinks and dishes; opening of establishments with national and regional cuisine in the format of coffee shops, pubs, confectioneries and fast food. [1-4]

Restaurateurs are especially interested in craft food and beverages due to the possibility of reducing costs, as in recent years there has been a steady increase in prices for imported products. [9] Local products are a great alternative to imported counterparts at a good price. [1, 9]

In recent years, many domestic craft winemakers have emerged that are little known in Ukraine. When consumers come to buy Ukrainian wine in a store or order a glass of wine in a restaurant, they often prefer global producers. However, the quality of Ukrainian wines is not much inferior to the wines of their European counterparts, and there are more and more of them every year [2-4]. Some aspects of the development of winemaking and production of craft products are considered in the works of such authors as M. Il'chuk, M. Dmytruk [5], V. Obniavko [6], L. Kalinichenko [9].

Thus, the restaurant market in major tourist cities has almost no establishments that could demonstrate the potential of craft wine products from Ukraine's wine regions to foreign guests.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The object of the study is a restaurant product based on the concept of a local restaurant with Ukrainian craft wines.

The subject of the study is a set of theoretical, methodological and applied aspects of creating a restaurant product with craft wine products.

Research methods: SWOT analysis, analysis of microenvironment factors, methods of qualitative and quantitative marketing research.

IV. RESULTS

Recently, restaurateurs and entrepreneurs have been paying a lot of attention to local, natural products because they are environmentally friendly, and they promote national products grown in Ukraine, reducing production costs by reducing the cost of product delivery. This trend will eventually lead to the development of farms and the economy of our country.

When developing the concept of the restaurant, we chose craft wines because it is a product that is quite unique, interesting and economically attractive. Craft wines are produced in limited quantities, so some of the wines presented in the restaurant are available in limited quantities. This is what attracts visitors who want to try something new for themselves and get acquainted with unique Ukrainian wines.

The promotion of national Ukrainian products is growing every year, and after all the political events in Ukraine, it will be popular not only among Ukrainians but also around the world.

In order to develop a restaurant product with craft wine products, the following tasks were set to be solved:

- to get acquainted with the literary sources describing the issues of organizing local restaurants with craft products;
- to analyze the restaurant market in the of Odesa city;
- to study the preferences of potential customers;
- develop a concept for a restaurant with craft wines;
- to model the restaurant infrastructure;
- develop a production program for the restaurant;
- develop the organizational structure of the restaurant management;
- model basic and additional services;
- develop a space-planning solution and design of the restaurant.
- assess the investment attractiveness of the proposed restaurant product.

4.1. Analysis of the restaurant services market in the of Odesa city

The restaurant services market in Odesa is developing very dynamically: the number of various cafes and restaurants is increasing, the range of food and beverages is improving, new and unusual concepts are being developed, and the culture of food consumption is widely developing.

The growth rate of the number of enterprises in Odesa is 14.1% higher than in other cities of Ukraine [11].

The existing restaurant business in Odesa includes more than 800 establishments of various types.

The following national cuisines are represented in Odesa:

- Ukrainian;
- Georgian;
- Oriental;
- European.

Recently, restaurant establishments with interesting, fashionable trends have begun to develop in Odesa [12], such as:

1. Enterprises offering craft products: beer, cheese, yogurt, wine.
2. The trend of coffee consumption is growing, and coffee shops of various types are widely developing.
3. A healthy lifestyle is very popular, and in this regard, more and more establishments of proper nutrition, cooking in the presence of guests from farm, ecological and fresh products appear on the market.
4. Delivery of products "from the ground to the table" is popular.
5. The introduction of culinary schools, master classes, and children's culinary schools in restaurants is at its peak, which contributes to the development of the art of cooking and eating.
6. Author's cuisine is gaining popularity among various establishments, which allows for a creative approach to cooking different dishes, creating your own product, and attracting great consumer attention.
7. Ukrainian formats have begun to grow in the city, in particular, an increase in interest in national cuisine in its various local manifestations based on recipes from different regions, but in a modern format, because the restaurant industry is developing rapidly, and national cuisine must be on the market as an identification of Ukraine and the Ukrainian people.

In Odesa, the dynamics of opening new establishments was positive, and despite the difficult economic situation in the country and in particular in Odesa, the number of profitable restaurant business enterprises is 56.3% [13].

The Odesa city takes a leading position in the country in the development of various enterprises and the factor that influences the development is the growth of wages and, as a result, there is a greater consumption of restaurant services.

4.2 Marketing research

Respondents aged 20 to 60 took part in the study, as they can be potential customers and provide clear information for the research.

The total number of participants who took part in the study was 100. The survey was conducted in electronic format in Google Forms.

The study was conducted on the following topics:

1. The main motives for visiting restaurants by potential customers.
2. Taste preferences of potential customers.
3. Frequency of visiting restaurants by potential customers.
4. Importance when choosing a restaurant.
5. Wine regions preferred by visitors when choosing wines
6. Wines preferred by visitors.
7. Taste properties of wines that visitors like.

The research algorithm included the following steps:

1. Creating questionnaires in Google Form.
2. Search for respondents.
3. Sending out questionnaires.
4. Receiving data.
5. Grouping and processing data.
6. Creating tables based on data in Exel.
7. Creating graphs.

According to the survey results, the main motivations for visiting establishments are the opportunity to communicate with family (23%), friends (22%), pleasant atmosphere (20%), and delicious food and drinks (16%).

According to the results of potential customers' taste preferences, the first place is occupied by menus with dishes of several cuisines (41%), focus on one cuisine (28%), and Ukrainian cuisine (19%).

Also, the survey participants said that 34% visit a restaurant once a month, 2-3 times and a month - 42%, once a week - 15%.

Regarding the importance of various factors when choosing an establishment, the following answers were received

- Politeness of the staff -16%;
- The atmosphere of the establishment -8%;
- Cleanliness - 14%;
- Menu - 11%;
- Speed of service -7%;
- Interior - 6%;
- Location - 5%;
- Average check - 6%;

- Drink list - 9%;
- Availability of parking - 5%;
- Popularity of the establishment - 4%;
- Number of guests - 3%;
- Additional services - 5%.

According to the research, the first place when choosing a restaurant by potential customers is the politeness of the staff - 16%, the next most important factor is cleanliness - 14%, the menu - 11%, then the drink list - 9%, and the atmosphere in the restaurant - 8%. Such factors as the number of guests - 3%, popularity of the establishment - 4%, turned out to be not so important when choosing a restaurant.

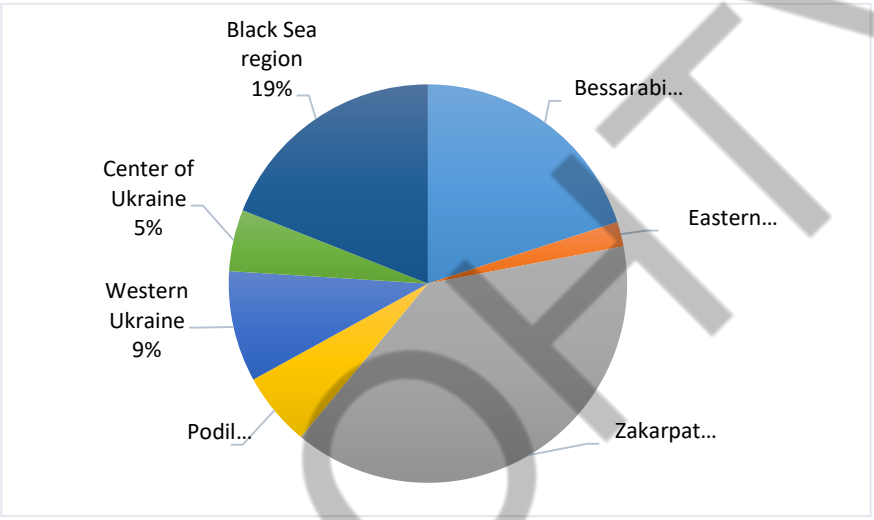

Fig. 1. Wine regions preferred by visitors when choosing wine drinks

As shown in Fig.1, the Zakarpattia region ranks first with 39%, followed by Bessarabia with 20%, and then Black Sea region with 19%. Less popular or little-known were the Western region (99%), Podillia (6%), the Center of Ukraine (5%), and the Eastern region (2%).

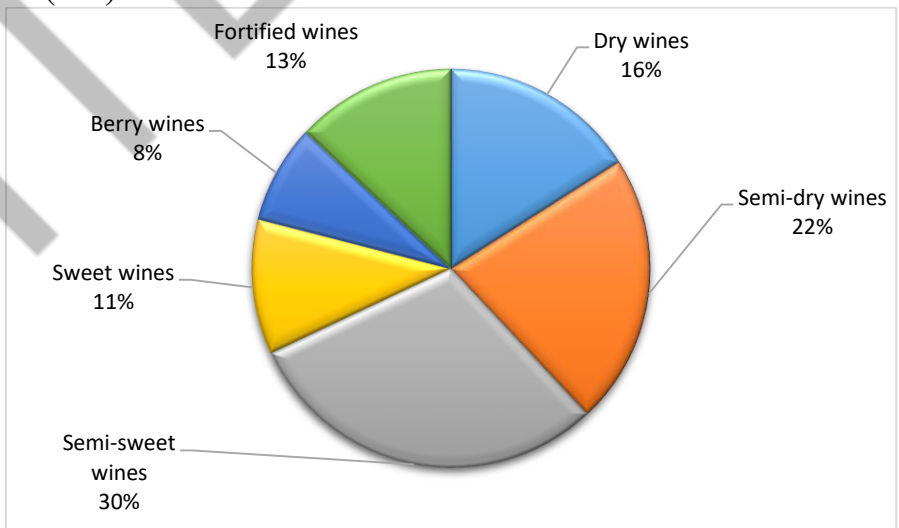

Fig. 2. Taste preferences of respondents regarding the type of wine

The first place (Fig. 2) is occupied by semi-sweet wines (30%), followed by semi-dry wines (22%), dry wines (16%), fortified wines (13%), sweet wines (11%), and berry wines (8%).

A survey of potential customers is very important in the formation and development of a new concept for a restaurant, since the restaurant business is directly related to the taste preferences of visitors. During the survey, you can find out what customers like and then, based on all the information, create an establishment that will be attractive, profitable and loved by customers. Customer opinions and preferences are the basis for the formation of a new concept.

If you focus on a certain contingent of visitors and listen to their opinions when creating a restaurant, this will lead to business prosperity. Customers will come to the establishment they like, and most potential customers will become regular customers, which accounts for 80% of the success and profitability of the establishment.

Based on the results of the research, we can conclude that Ukrainian wines are a very attractive and relevant topic for many restaurant visitors. As it turned out, many visitors would gladly come to a wine restaurant.

Based on the research, we can also say with certainty that red semi-sweet wines, red semi-dry wines, followed by white semi-sweet wines, and sparkling wines are in the greatest demand.

Rosé, berry and fortified wines were less popular among respondents, although some visitors are very fond of fortified wines for their rich flavor.

4.3. SWOT analysis of the local wine restaurant, analysis of restaurant competitors

The SWOT analysis of a local wine restaurant showed that the strengths and opportunities of this restaurant will be the following characteristics:

- the prospect of reaching the level of a top-class restaurant
- large flow of visitors
- increase in the level of service
- increase in additional services
- the possibility of holding various interesting events
- expanding the map of craft wines
- creation of attractive restaurant advertising.

Weaknesses and threats for a local restaurant will be such events as:

- high competition in the restaurant services market
- unstable political and economic situation
- military actions on the territory of Ukraine
- power outages
- decrease in income of the population
- changes in the exchange rate
- high taxes.

There are many restaurant establishments in the city of Odesa, but the main competitors of the future local restaurant "Paradis Wine" are 4 wine restaurants, such as:

- Bernardazzi;
- Bruno;
- Fratelli;
- YUG;

Brief description of the establishments:

1. Restaurant "Bernardazzi"
Location: Odesa, 15 Bunina str.
Cuisine: multinational
Average check: 700 UAH.
Special features: Bernardazzi restaurant has one of the largest wine collections in Ukraine. Tastings are held in this restaurant.
2. Restaurant "Bruno"
Location: Odesa, 14, Grecheskaya str.
Type of cuisine: Flemish
Average check: 550 UAH
Specialties: a combination of French and Italian cuisine.
Wines from different parts of the world.
3. Restaurant "Fratelli"
Location: : Odesa city, 17, Grecheskaya str.
Type of cuisine: Italian
The average check: 800 UAH
Specialties: naturalness and quality of natural and high-quality Italian cuisine.
Drinks are treated with special care: they use only their own purified water, and put a minimal markup on wine.
4. Restaurant "YUG"
Location: Odesa, Mayakovsky lane, 15
Type of cuisine: multinational
Average check: 500 UAH
Special features: the restaurant is located on the seashore. Each dish is labeled with a symbol of the country from which it was borrowed.
The wine list is 14 pages long and includes drinks from all over the world.
All these establishments are wine restaurants with interesting and rich wine lists of wines from around the world. Multinational cuisine prevails in the establishments.
Compared to its competitors, Paradis Wine's restaurant product will be distinguished by its Ukrainian product - Ukrainian craft wines and local Ukrainian products combined with innovative technologies.

4.4. Development of a local restaurant concept

The concept of the restaurant is to present Ukrainian craft wine in a new way in a local restaurant.
The restaurant has interestingly selected and created dishes that combine European cuisine with modern Ukrainian cuisine, discover and emphasize the taste of Ukrainian wine. A wide list of Ukrainian craft wines, which are made and collected from all over Ukraine.
All dishes and wine drinks at «Paradis Wine» restaurant are successfully selected with the help of enogastronomy, which has certain rules. The dishes in the restaurant are designed in such a way that they all go well with certain types of wine and help to reveal its taste.
The wine list at Paradis Wine restaurant contains only craft wines that are produced exclusively on the territory of Ukraine and in small quantities, and have their own uniqueness and originality.

All the details in the restaurant, from design to the choice of dishes and drinks, are matched to the same style to show the essence of the Paradis Wine concept.

The restaurant has also introduced interesting additional services, such as organizing presentations of craft wines by famous sommeliers, which is very attractive to visitors. The SMM manager negotiates with the sommelier, organizes the presentation, chooses the day of the event, and informs guests about the event.

For fast service, the restaurant has implemented touchscreen menu displays, where guests can choose the dishes they like.

Guests can find information about wine and dishes on the menu, and there are recommendations for each wine drink.

The menu of the Paradis Wine restaurant provides such information as:

- Type, taste and history of the wine drink;
- Recommendations for the correct selection of dishes for wine;
- Photo of the dish;
- Ingredients;
- Serving;
- Pricing policy;
- Discounts;
- The number of dishes.

The guest chooses and adds a dish and a drink, the number of servings. Also, in a special form, he can enter his wishes for the dish or the exclusion of ingredients from the dish according to his characteristics. At the guest's request, they can place an order with the waiter. After the guest confirms the order, the information appears in the kitchen, where the chefs immediately prepare and arrange the dish for the waiter, serve drinks and set the table with the necessary utensils. This allows for quick interaction between the guest, chef, waiter, and sommelier. While the guest is waiting for their order, they can learn more about the drink they have chosen.

The restaurant's dishes are prepared exclusively from Ukrainian, local products.

The restaurant's design is created in the style of a modern loft, with wine bottles, glasses and barrels.

The name of the restaurant "Paradis Wine" was chosen to show the majesty and originality of Ukrainian wine.

Additional services of the restaurant "Paradis Wine"

The restaurant will be widely represented by such additional services as:

- master classes, presentations of new wines, producers and sommeliers;
- creation of the "virtual cellar" application - an application for wine lovers and connoisseurs. In the application, you can quickly take a picture of a bottle of wine and, after evaluating its taste, write a couple of notes, and then save it in a virtual cellar;
- Wi-Fi;
- music and entertainment;
- discount system;
- taxi call;
- table reservation;
- packaging of products purchased in the restaurant;
- acceptance of bank cards for payment.

Algorithm of guest service in the restaurant "Paradis Wine"

1. Preparation of the restaurant for opening.
2. Opening of the restaurant.
3. Meeting the guest.
4. Accompanying the guest to the table.
5. The guest chooses a dish and confirms the order.
6. The order immediately appears in the kitchen and at the waiter.
7. The cooks prepare and decorate the dishes.
8. Waiters set the table and serve drinks while the food is being prepared.
9. Sommeliers serve wine or wine drinks.
10. Serving and presenting the food to the guest.
11. Consumption of food by the guest.
12. Serving the guest.
13. Calculation.

Enterprise development strategy and its justification

Sources of additional profit of the restaurant "Paradis Wine":

1. Interest received for keeping funds in bank accounts.
2. Income from operations with containers, amounts received from suppliers as reimbursement for the costs of collecting, storing, loading, and transporting containers.
3. Markup for specialty dishes.
4. Revenues from additional services.
5. Cooperation with a taxi company, percentage of the client.
6. Revenue from the sale of foreign currencies.
7. Income from the revaluation of finished goods and goods.
8. Discounts from suppliers.
9. Payment by bank card, accumulation of %.

4.5. Strategy of the advertising company (main types of advertising) of the restaurant "Paradis Wine"

1. Placement of banners near the restaurant.

A noticeable original drawing with an interesting inscription and design, creative imagination attracts the attention of consumers.

2. Advertising leaflets.

Postcards are concise, clear and memorable, which is an additional percentage of customers.

3. Restaurant emblem.

The emblem is an important element of restaurant advertising. For a good effect, the restaurant has a stylish and interesting emblem. Also, the emblem is on the clothes of employees and in the design of the establishment.

4. Advertising on social media.

A beautiful, stylish and easy-to-use account on social networks: Instagram, Facebook.

5. Cooperation with bloggers who have a wide audience.
6. Create your own website.
7. The restaurant website is stylish, lightweight, contains all the necessary information and attracts customers.

8. The quality of the restaurant.

One of the best advertisements is excellent quality, an interesting concept, and high-quality service. If a customer likes it, he or she is one of the potential, regular customers of the establishment, and it is very effective.

Choosing a method of promotion and sales

One of the best and most effective methods of promoting a restaurant is word of mouth (WOW marketing). But, of course, you also need classic business promotion. And the choice and creation of a promotion method must be approached correctly. Promotion cannot do without advertising.

Promotion is necessary for:

- informing;
- persuasion;
- reminding;

Stages of restaurant promotion:

1. Identification of the target audience.
2. Correct formation of goals.
3. Appeal to the consumer.
4. Development of promotion methods.
5. Selection of media sources.
6. Determining the budget.

Promotion of the restaurant:

1. Entering the market.

At this stage, it is faster to inform future consumers about the opening of the establishment.

You can inform them in the following ways:

- advertising in social networks;
- advertising brochures.

2. Growth and development.

Sales and visits to the restaurant are growing. At this stage, the consumer knows about the restaurant and needs to be interested.

The consumer can be interested in the following methods:

- interesting menu;
- delicious food and drinks;
- interesting additional services;
- quality service.

3. Maturity.

Growth continues, but the pace is not as fast. It is necessary to be different from others, to be interesting, attractive and of high quality. This can be achieved through an interesting concept of the establishment, the introduction of new additional services.

4. Rejuvenation.

You need to encourage customers to visit the restaurant more often.

This can be done through the following methods:

- introduction of a new assortment;
- expanding the wine list;
- introduction of new services;

- introducing a system of discounts for regular customers;
- compliments from the chef.

Promotion and sales are very important for a restaurant, as it affects the operation of the establishment, the formation of the customer base, and the profit from the establishment.

4.6. Suggestions for the design of the restaurant

The design of the restaurant "Paradis Wine" is made in the style of a modern loft with the use of modern construction and design technologies. The design of the restaurant is created and matched to the style of the wine restaurant. All the details are clearly selected for the wine restaurant.

The color scheme of the restaurant is made in dark, restrained colors. The walls in the restaurant are made of natural stone, which gives visitors the idea that they are in wine cellars, which conveys the atmosphere of the restaurant itself very well. Fig. 3 shows the design of the walls of the Paradis Wine restaurant.

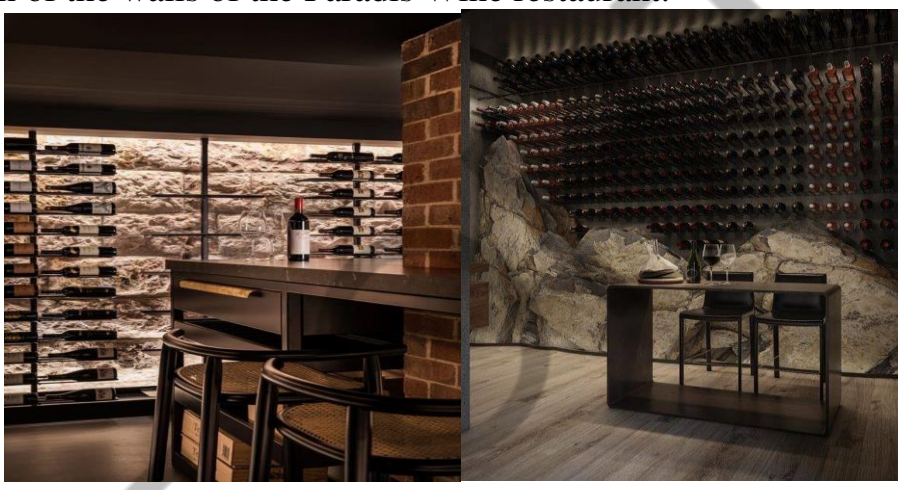

Fig. 3. Design of the walls of the “Paradis Wine” restaurant

The walls of the hall are decorated with illuminated shelves, and wine bottles are placed on the shelves themselves. The ceiling in the restaurant is made of wine glasses with built-in lighting, which gives the place the necessary atmosphere of a wine restaurant and fits well into the design and concept of a local wine restaurant.

The restaurant "Paradis Wine" has a specially made to order bar counter, behind which there are also bottles of various wine drinks.

The furniture in the wine restaurant is made to order in the loft style. Square-shaped tables made of real wood. The chairs are made of brown leather. In the lobby of the restaurant, the walls are made of stone, and there is a large mirror with lighting. All interior details and decor are made in loft style and perfectly match the concept of the restaurant.

V. CONCLUSIONS

So, as a result of creating the concept of a local restaurant, a restaurant product was developed - a menu and a wine list of Ukrainian craft wines. The wine list of a possible local restaurant "Paradise Wine" includes wines from various family wineries from all wine regions of Ukraine - Bessarabia, Black Sea, East, West, Podillya, Zakarpattia, and Central Ukraine. Promoting craft wines will allow us to introduce more people to interesting Ukrainian wines and talented Ukrainian winemakers.

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ADDENDUM A

Menu plan of the local restaurant "Paradis Wine"

Name of dishes	The output of dishes, g	Number of dishes per day
Cold appetizers and salads		
Set of meat delicacies and cheeses	600	24
Cheese and fruit set	600	14
Salmon carpaccio	300	35
Veal carpaccio	300	24
Salmon bruschetta	300	4
Nachos chips with cheddar sauce	250	3
Cheese plate	500	15
Hummus with fresh vegetables and homemade cheese	300	10
Bruschetta with shrimp, avocado and cucumber	150	4
Appetizer of dried salmon with salmon caviar in cucumber	200	3
Smoked fish pate with cranberries and lime on toast	200	35
Pate with chicken liver	200	24

Seasonal fruit platter	400	13
Ravioli Fujin	250	13
Salad with veal and chicken liver	250	13
Salad with avocado, feta cheese and seasonal berries	250	15
Salad with salmon, asparagus and poached egg	250	15
Salad with jamon, arugula, tomatoes, nuts and raspberry sauce	250	16
Caesar salad	250	17
Hot appetizers		
Baked Haloumi cheese with jam	250	19
French fries with parmesan and truffle cheese sauce	250	28
Baked pear with Camembert, honey and nuts	250	20
Bacon with peach and balsamic glaze	250	28
Рулетики з куркою та смаженим перцем	250	30
Chicken thighs stuffed with mushrooms and feta	250	25
Roast pork brisket with apple puree and cider vinegar dressing	250	26
Soups		
Гаспачо з огірком, мигдалем з грінками	320	9
Крем-суп з буряка	300	8
Грибний крем-суп	300	10
Суп з локшиною	300	16
Борщ український	300	10
Hot dishes (main dishes)		
Pasta with salmon and spinach	250	5
Grilled chicken breast on baked eggplant in teriyaki sauce with olive topenado	300	13
Pasta with seafood from durum wheat	250	5
Glazed chicken wings with sweet chili sauce	300	14
Chicken baked with mushrooms and cheese on a bed of mashed potatoes	300	13
Ravioli with ricotta, sun-dried tomatoes and pesto sauce	300	5
Chicken rolls	300	11
Caramelized pork ribs in honey glaze	300	10
Salmon steak with spinach sauce and broccoli vegetables	250	29
Pike perch with ratatouille vegetables	300	29
Polenta with dried spinach and mushrooms	300	4
Oven risotto with crispy fried mushrooms	300	5
Mashed potatoes	150	8
Baked potatoes	150	7
Veal tenderloin steak	250	12
Steak "Mignon"	250	12
Ribeye steak	250	12
Sweet dishes		
Honey cake with cherries	150	11
Classic Honey cake	150	10

Strawberry cheesecake	150	9
Red velvet	150	10
Caramel Oreo	150	8
Pistachio whim	150	10
Slender dessert with berries	150	12
Hot beverages of own production		
Expresso	30	10
Americano	60	20
Cappuccino	150	15
Latte	200	15
Flat white	200	12
Dopio	150	10
Raf -coffee	200	5
Matcha latte	200	5
Classic black tea	250/400	15
Black tea with bergamot	250/400	15
Classic green tea	250/400	15
Green tea with jasmine	250/400	15
Tea with fruit and berries	250/400	15
Cold beverages of own production		
Fresh orange juice	250	
Fresh grapefruit juice	250	
Fresh apple and carrot juice	250	
Pomegranate fresh	250	

ADDENDUM B

WINE LIST
CRAFT WINES OF UKRAINE
Standard bottle

Name	Alc. %	Year	Region	Grape	Price UAH.
Sparkling Wine					
Bisser, Brut, *Kolonist*	10,5	2020	Bessarabia	Chardonnay	545
Artania Pet Nat, Brut, *Beykush Winery*	11,5	2021	Black Sea Region	Pinot Gris, Riesling	585
46 Parallel El Capitan, Brut Rose, *46 Parallel*	11,5	2020	Bessarabia	Pinot Meunier	417
Beresagne, Brut Rose, *Beykush Winery*	11,5	2015	Black Sea Region	Pinot Noir, Pinot Gris, Tempranillo	1170
White Wines					
Traminer, Table dry white wine, *Kolonist*	12,5	2015	Bessarabia	Pink Traminer	150
Sukholimanskiy 2017 Villa Tinta, Dry white wine, *Vinhol Oksamytne LLC*	12	2017	Bessarabia	Sukholimanskiy	149
Chardonnay 2018 Villa Tinta VIP Collection, dry white wine, *Vinhol Oksamytne LLC*	12	2018	Bessarabia	Chardonnay	185

Rkatsiteli, dry white wine, *Frumushika-Nova family winery*	11,4	2019	Bessarabia	Rkatsiteli	215
Vintage Grand Cuvée Chablis Style, Private Reserve, *Don Alejandro Winery*	12	2016	Black Sea Region	Riesling, Chardonnay	480
Aged Furmint, Dry white wine, *Chateau Chizay*	12	2017	Zakarpattia	Furmint	495
White Triangle, Dry white wine, *Father's Wine*	11	2020	Podillya	Johaniter	390
Pinot Blanc/Sylvaner *Biologist Craft Winery*	12,5	2021	Central Region	Pinot Blanc, Sylvaner	350
Citron Magaracha 2019, Dry white wine, *Craft winery TM "Wines of Zaporizhzhia"*	12	2019	East Region	Citron Magaracha	320
Solaris, Dry white wine, *"Château Edem"*	13,4	2019	Western Region	Solaris	1200
Rosé Wines					
Artania Pink, Dry pink wine, *Beykush Winery*	13,5	2018	Black Sea Region	Pinot Gris	235
Rosé Alia Terra, Dry pink wine, *Teruar Farm*	12,5	2020	Zakarpattia	Zweigelt, Cabernet Sauvignon, Merlot	550
Barbaryska Rose, Dry pink wine, *Bohdan's winery*	12,5	2020	Podillya	Sangiovese	350
Red Wines					
Velvet of Ukraine, Vintage dry red wine *Winery of Prince P.M. Trubetskoy*	13	2015	Black Sea Region	Cabernet Sauvignon	270
Merlot, Dry red wine, *V.Petrov Winery*	13	2020	Bessarabia	Merlot	350
Odesa Black, Dry red wine, *VINOPION winery*	13	2020	Bessarabia	Odesa Black	280
Cabernet Reserve, Dry red wine, *Winery "Gulievs' Wines"*	13,2	2016	Black Sea Region	Cabernet Sauvignon	324
Treasures of Bredihin, Dry red wine, *SliVino Village*	13,2	2019	Black Sea Region	Cabernet Sauvignon	220
Cabernet Reserve, Dry red wine, *Leleka Wines*	13	2019	Bessarabia	Cabernet Sauvignon	239
Odesa Black, Dry red wine, *Kolonist*	13	2020	Bessarabia	Odesa Black	369
The face, Dry red wine, *Father's Wine*	13	2020	Podillya	Merlot, Cabernet Sauvignon	499
Odesa Black, Dry red wine, *Biologist*	14	2019	Central Region	Odesa Black	637
Pinot Noir, Dry red wine, *Cassia Family Winery*	11,5	2020	Central Region	Pinot Noir	380
Bastardo, Dry red wine, *Driukivski Wines winery*	11,5	2019	East Region	Bastardo	350
Cabernet Sauvignon, Dry red wine, *Igor Zaika's family winery*	12	2017	East Region	Cabernet Sauvignon	300

ANTI-CRISIS PROGRAMS FOR RESTAURANT MANAGEMENT IN MODERN BUSINESS CONDITIONS

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Abstract. *The aim of the article is the study of presumable and real causes of the crisis, the factors that cause it, its signs and consequences that deteriorate the normal conditions of the enterprise functioning. Research methods used in the process of writing the work include general and special methods. From general research methods the following were used: deduction (when constructing the structure of work in the logical interconnectedness and unity, as well as the interdependence of its components), induction (when forming general conclusions of the study), abstract logic and synthesis (when clarifying the interpretations of the categorical tools of crisis management), analysis (in the development of classifications of crisis phenomena, in the study of trends in restaurants crisis management, in processing the results). Special methods used include factor analysis, computational analysis and method of comparisons, tabular and graphic, economic and statistical correlation analysis, forecasting methods (in justifying the prospects of institutions) restaurant business after the cessation of the spread of the coronavirus pandemic) and other methods of studying economic and managerial processes and phenomena. This paper investigates the system of restaurant crisis management and defines its essence and main components. It also considers necessity and relevance of crisis diagnostics and monitoring of restaurants activities and operations during different crisis lifecycle stages. The present work includes a comparison of foreign and Ukrainian experience, as well as the practices of crisis management and reorganization, state regulation in the realm of bankruptcy. It establishes the main external factors of unprofitable activity of restaurant establishments. It determines that the innovation policy in the crisis management process is one of the main tools that contributes to the exit of the establishments under study from the crisis and increase their competitive positions in the market. The current study presents a generalized sequence of crisis management strategic goals implementation. It identifies the phases of the crisis development and the stages of the crisis lifecycle in the restaurant business. It shows the developed structural organisation of restaurant establishments under the influence of the anti-crisis action program. Also it presents specially developed proposals to reduce electricity costs in the restaurant business. This research offers motivational components that are recommended for introduction into the establishments activities and presents the structural model of restaurants activity crisis management system.*

Key words*: crisis management, motivation, bankruptcy, crisis diagnostics, innovation policy, reorganization, capacity to pay, liquidity.*

I. INTRODUCTION

In today's volatile economic environment and amidst the Covid-19 pandemic, the efficiency of the restaurant industry fuctioning, as well as its capacity to pay, profitability

and liquidity of assets are significantly influenced by many factors, including low purchasing power of consumers, ban on the activities of restaurants during lockdowns and their restrictions on the provision of services, jumps in exchange rates, as well as negative endogenous factors such as low level of management or insufficient staff training, weaknesses in production and marketing, lack of innovation policy.

Many restaurateurs do not even count the losses, because the work of their establishments has almost completely stopped. Therefore, the quarantine, which began due to the spread of the coronavirus, can be called the biggest crisis in the history of the Ukrainian restaurant business.

Under such conditions, a rapid response of managers (prompt Crash-program), efficient crisis management, mobilization of internal resources is needed [1]. An effective way out of the crisis is the use of crisis management procedure, which involves the introduction of production and technical measures into the restaurant activity system, the use of external and internal reserves to restore profitability and avoid bankruptcy.

Financial recovery as an integral part of crisis and bankruptcy management includes a targeted selection of the most effective tools, strategy, tactics needed for a particular type of business. The individuality of the choice of these means does not mean that there are not any generalized means, characteristic of all enterprises in financial crisis. Studying the experience of overcoming crisis situations of both different countries and specific enterprises allows to form a flexible system of crisis management.

II. LITERATURE ANALYSIS

The crisis of the economy threatens any company, including restaurants, with not only financial problems and market position weakening, but also the loss of qualified personnel, without which it is impossible to ensure the survival of the company in crisis situations, confirmation of its competitiveness or successful business management in the future. This problem was considered in the works of E. Altman, W. Beaver, M. Holder, D. Keynes [6], J. Conan, R. Lees, D. Ricardo, R. Taffler [3], G. Tyshaw [3], and others. In this context, the works of domestic authors, such as: I. Blank, V. Vasylenko, I. Yepifanova, L. Ligo-nenko, H. Ostrovska, N. Oranska, I. Povo-rozniuk, V. Samoilenko, L. Sytnyk, O. Steshenko, O. Tereshchenko, T. Charkina, and others. and others.

The analytical and research organization Hotel & Destination Consulting (HDC) pays considerable attention to the problems of the development of hospitality industry enterprises in its research.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The hotel industry of Ukraine is the main infrastructural component of the hospitality sector of Ukraine, but recently it has been developing in crisis conditions caused by the COVID-19 pandemic, the war in the east of Ukraine and the recession of the financial and economic system, which is characterized by a drop in tourist and business activity, insufficient funding, low the level of diversification of services, long-term payback of investment projects, etc.

Currently, the demand for hotel services due to the pandemic is low, and the losses caused to the market are significant. According to a study by the Association of Hotels and Resorts of Ukraine (UHRA), 93% of surveyed hoteliers confirmed a general decline in the level of their hotel's revenue in 2021, 21% of hotels saw their gross revenue decrease by 25–40%, and a third of hotels – by 40–60 %, in 30% of hotels such reductions reached more than 60%, only 4% of hotels showed an increase in annual revenue, and in 3% it remained at the same level (Ukrinform, 2022).

This state of hotel enterprises prompts them to change their existing and implemented development of new directions of functioning, increasing the flexibility of activity, which is usually characterized by riskiness and does not always give positive results, and sometimes can lead to the emergence of complex crisis phenomena. Therefore, in modern conditions, the implementation of an effective system of anti-crisis management, which will ensure the solution of existing operational problems, the exit from difficult crisis situations, the restoration of stable functioning and further progressive development, becomes relevant. In a highly competitive, dynamic and uncertain environment, the functioning of such a management system should be accompanied by the implementation of active diversification measures that will contribute to strengthening the state of business entities on the market, gaining competitive advantages, and increasing the efficiency of operations.

The purpose of the work is to develop recommendations for improving the anti-crisis management system of a hotel enterprise, taking into account the stage of its life cycle, the index of diversification potential and the level of development of the anti-crisis management system. The object of the study is the process of improving the anti-crisis management system of hotel enterprises.

IV. RESULTS

Anti-crisis management as a system of principles and methods of development, implementation and implementation by the hotel management of a set of special management solutions aimed at preventing and overcoming crisis phenomena in the hotel, one of the tasks is to preserve competition on the market.

It is important to focus on the proposed directions as a whole, and not separately from each other - only in this case can you achieve the maximum synergistic effect life cycle of a hotel enterprise;

− determination of the level of development of the anti-crisis management system of the hotel enterprise based on the analysis of functional components (anti-crisis planning, anti-crisis organization, anti-crisis motivation, anti-crisis control);

− determination of the diversification potential index of the hotel enterprise;

− choice of diversification strategy activities of a hotel enterprise, taking into account the stage of the life cycle, diversification potential and the level of development of the anti-crisis management system;

− development of measures to improve the anti-crisis management system of a specific hotel enterprise.

During times of crisis, many businesses develop diversification strategies, which may simply be active tactics for the short term or more fundamental strategic changes for the medium to long term.

Some businesses will eventually return to "normal" operations (or the "new normal"), then how others will be completely transformed, with a new business model (business formula). Some creative entrepreneurs will use the opportunity to change the "design" of their business, adapt to new realities and achieve even greater success.

The system of restaurant crisis management is a set of coordinated elements that, interacting with each other, diagnose the signs and manifestations of the crisis, help to overcome it and return business structures to stable functioning, create the necessary conditions for overcoming the negative impact of external and internal factors on the establishments activities.

The main purpose of restaurant crisis management is to create conditions for stable functioning of enterprises in the market in response to any economic, political or social transformations in the country, to develop strategic alternatives based on forecasting and anticipating the development of the situation, to avoid financial problems and overcome the threat of bankruptcy at the lowest cost, to introduce innovative changes in activity (fig. 1).

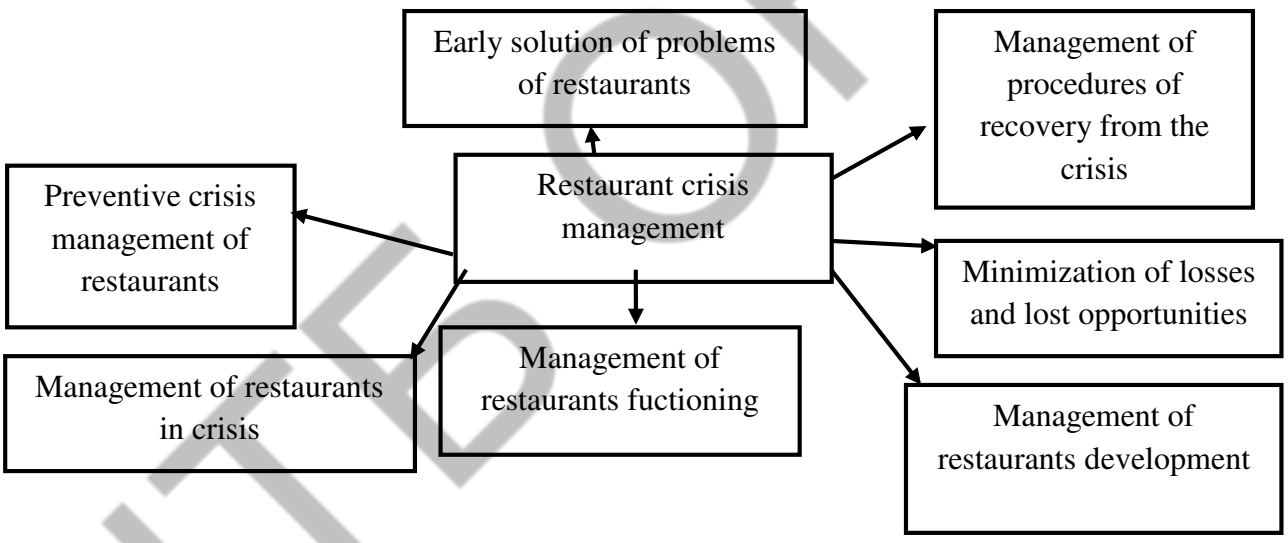


Figure 1 - The essence of restaurant crisis management

Source: Compiled by the authors

The main purpose of signs of crisis diagnostics in the restaurant industry is to prepare information for analysis and its initial processing to implement appropriate decisions on enterprise management, including anti-crisis measures, throughout the entire period of enterprise activity depending on the nature of the information received.

The results of economic diagnostics should be based respectively on the analysis of the current activity of the restaurant, preventive (previous) information and prospective analysis of the results of production, economic and financial activities of the enterprise. They as well should influence the development program for this restaurant and its strategic choice.

Restaurant crisis diagnostics can be schematically shown in Fig. 2.

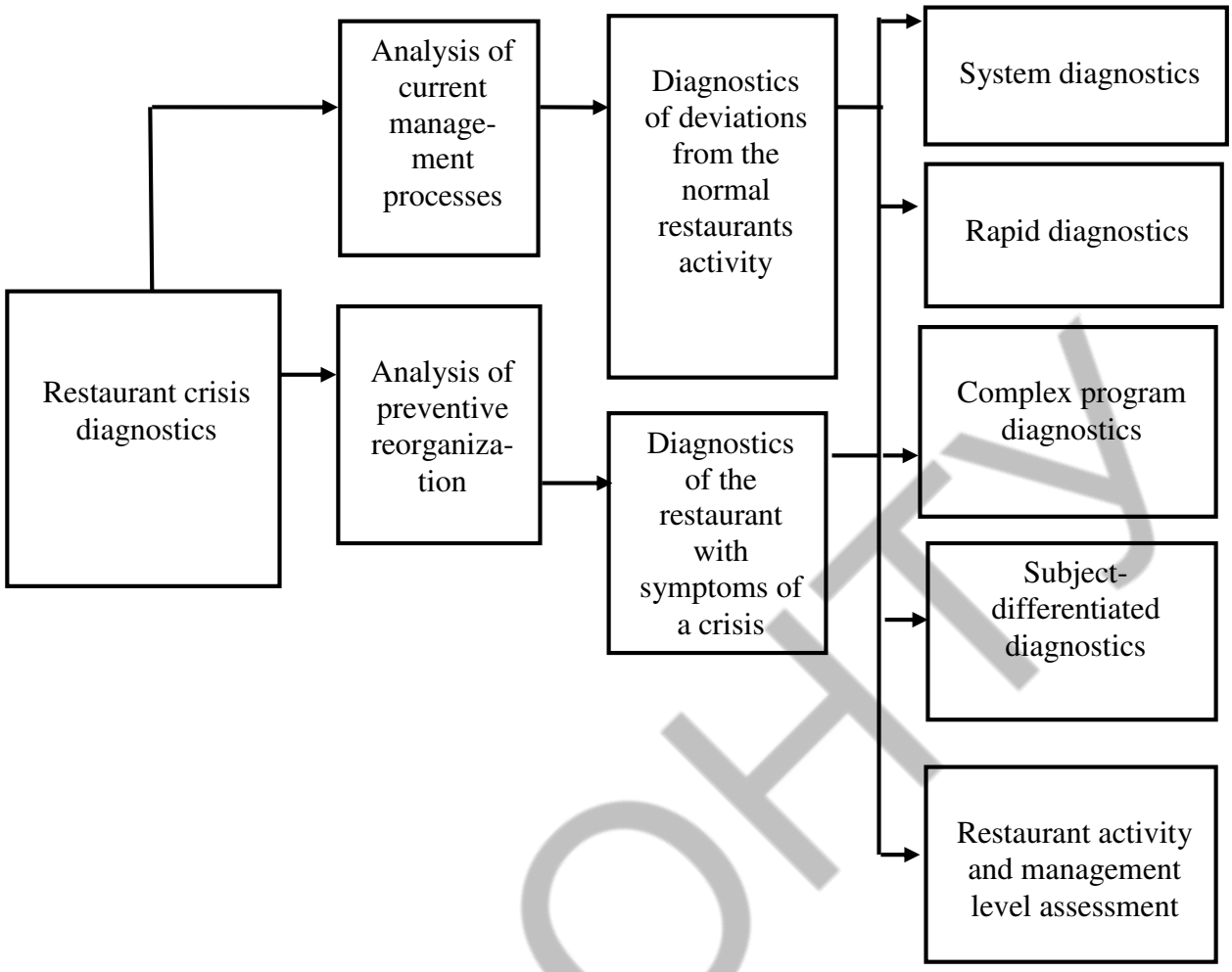


Figure 2 - Restaurant crisis diagnostics

* Compiled by the authors

This diagnostics and analysis of the crisis in restaurants depends on the stage of the crisis (Fig.3).

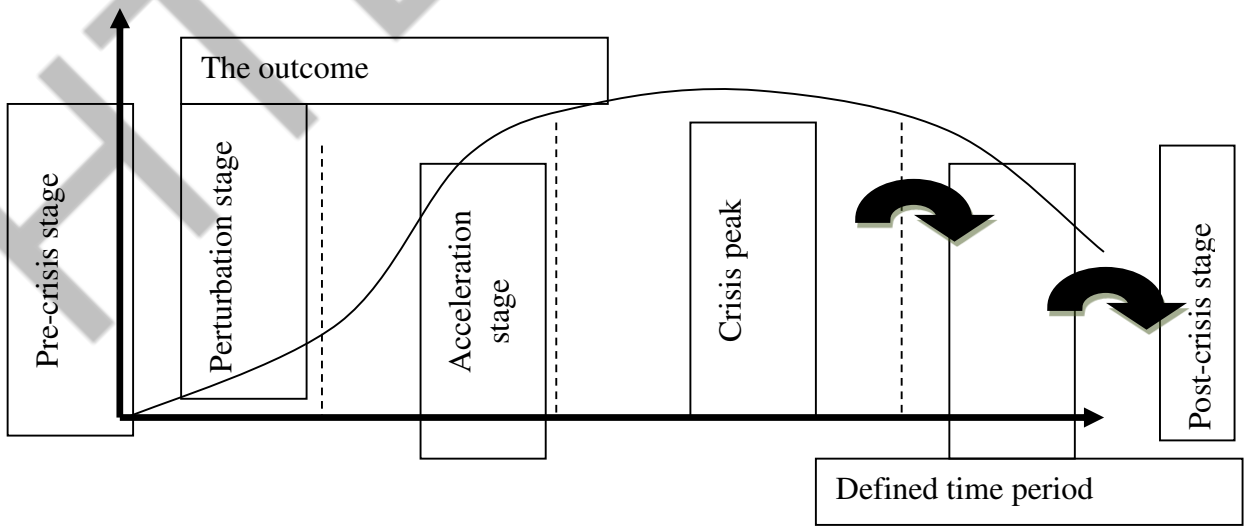


Figure 3 - Stages of the restaurant crisis lifecycle

* Compiled by the authors

Thus, as can be seen from Fig. 3, during the pre-crisis stage it is necessary to carry out a basic (fundamental) analysis of the possibility of crisis phenomena emergence, including the use of bankruptcy likelihood models and indicators (Altman method, Beaver method, Aaron Jones-Swory model, etc.), risk assessment methods (Monte-Carlo method, scenario analysis, critical limits method, peer review method, decision tree method), analysis of the industry emergencies, analysis of asset portfolio.

During the perturbation stage it is necessary to analyze the compliance of the implemented anti-crisis measures with the nature of the crisis: economic efficiency analysis in comparison with the average market value, analysis of the efficiency of asset portfolio differentiation, analysis of production and technical indicators of the enterprise, analysis of the correspondence between the costs of production and profit..

During the acceleration stage it is necessary to resort to the following methods of diagnostics: the use of probabilistic risk assessment methods (analogy method, sensitivity analysis, scenario analysis), alternative analysis of short-term prospects in the industry using technical stock market analysis.

Figure 3 highlights the last three stages. This applies to the crisis of restaurants, which began in 2019 due to the spread of Covid-19. No one expected such situation to occur, so the establishments were not prepared for this and therefore the crisis began with the "crisis peak" stage.

Taking into consideration the fact that during the lockdown restaurants were in the peak of the crisis, the analysis of their condition on the basis of current anti-crisis measures had to be carried out in accordance with the following methods: rapid financial ratios analysis (liquidity, financial stability, business activity, profitability), "DU PONT" model-diagram analysis, analysis of the dynamics of the crisis in the industry and technical analysis of the stock market.

In 2021, it will be difficult for restaurants to return to the normal activity. This stage also contains hidden risks, so a short-term analysis of the dynamics of negative manifestations and medium-term forecast should be performed by analyzing financial ratios, risk analysis and assessment, rapid analysis of business efficiency, comparison with competitors and market averages. During the deceleration stage it will be necessary to perform a fundamental analysis of lost opportunities, including in-depth analysis of business efficiency, the use of probabilistic risk assessment methods, assessing the impact of non-systematic risks.

The post-crisis state of the restaurants, which will begin with the end of quarantine restrictions and the complete cessation of the spread of coronavirus in Ukraine, will require constant analysis of this market. This should be done by monitoring the condition of these establishments and diagnosing possible threats, performing a comprehensive analysis of losses and conservation of capacity by analyzing the technical and organizational level and conditions of production, production resources, crisis prospects in the industry, and also by the use of global generalized indicators of bankruptcy likelihood, by assessing business and operational activity.

There is a very realistic chance that the coronavirus pandemic crisis has completely changed the restaurant market. The consumer has changed his priorities. During this crisis, the problem of security became especially relevant. During previous

crises, the biggest problems arose in the field of economic security. This crisis will not be an exception, which, unfortunately, will not end with the lifting of quarantine restrictions. With regard to food security, in the current epidemiological situation, it is especially important to pay close attention to it, because the price of error is a real threat to the lives and health of employees and consumers. However, we should not forget about economic, personnel, information and physical security. During the crisis, crime rates often increase, so it is necessary to conduct timely collection of money proceeds, regular audits of property. Risks in each area must be minimized.

Quality and timely diagnostics of restaurants will form an appropriate analytical basis for creating an anti-crisis program for these establishments, developing a set of relevant anti-crisis measures, and provide favorable conditions for the successful solution of problems connected with identification, prevention and overcoming such a crisis in the restaurant business [9, p. 89].

During the period of full lockdown, which was introduced in the spring of 2020 and in January 2021, these establishments were not allowed to work at all, only in the mode of delivery of their products. But not every restaurant has its own delivery. Furthermore, there is not much profit from delivery, because it does not involve all staff and can be carried out with a limited group of dishes from the restaurant menu. Most of the profits of restaurants are received from banquets, corporate events, which in 2020 were not actually held. Only some restaurants took risks to do it despite the bans and fines. Therefore, in order for restaurants to be able to stay afloat, it is necessary to develop a program of action, in compliance with which it will be possible to keep staff, pay all taxes and utility costs and get at least a minimum profit.

Taking into concideration the essence of restaurant crisis management in modern conditions, the following ways to avoid the crisis situation were revealed during this research (Table 1).

Table 1 - Recommended actions of restaurants in the event of a crisis

Recommended actions	Ways of application
1) Start delivery and earn money that can at least partially cover the payment of team salaries	This is important if team memebers have key skills, and the restaurant business owner wants to keep them at all costs. Or if it is a small bar or a family type establishment, and the team is really a family, and everyone is willing to work 150% to get at least 30-50% of the usual salary.
2) Get involved in volunteering.	Here as well it is necessary to understand what the resources are, how relevant this activity is for the restaurant business owner, how the team treats it, and so on. There are companies that have idle shops, and they prepare lunches for doctors to avoid this. Someone pays for products, and companies share their technology and equipment. There is also an idea with "suspended pizzas".
3) Stay in touch with the guest, producing not a product but content	For example, Massimo Bottura did it, launching a "quarantine cooking show". In fact, many restaurateurs and chefs are now producing more content. And there is nothing wrong with that. It is important that all these inputs, recipes, tips, broadcasts meet the real expectations and requests of people.

4) Don't try to keep pace with the others, but focus on systemic changes in the company that will allow you to quickly adapt to new conditions	Instead of keeping running to try to earn a few thousand hryvnias and spend much more, sometimes it is better to take a short break, realistically assess the strengths and weaknesses of your business and focus intellectual and creative efforts on rebuilding processes globally.

* systematized by the authors

Table 1 shows the tactics that can be followed by restaurants during the coronavirus pandemic, choosing for themselves those actions that are the most suitable for a particular type of establishment.

The structural organization of restaurants under the influence of the anti-crisis action program is shown in Fig.4.

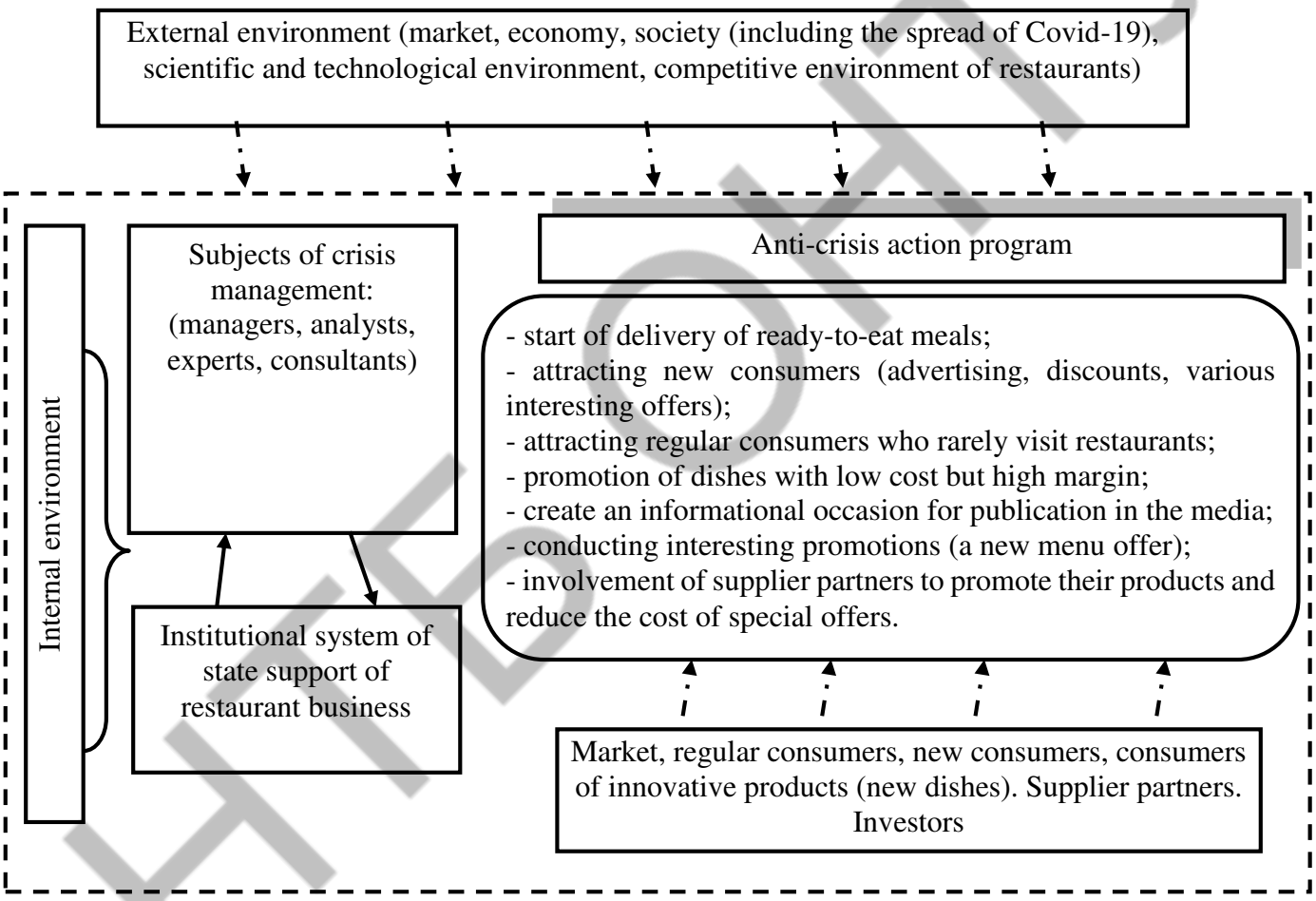


Figure 4 - The structural organization of restaurants under the influence of the anti-crisis action program

* Compiled by the authors

Resource saving also has a very important role to play in the work of restaurants. Electricity is the largest item of utility costs. The distribution of electricity costs in the studied restaurants is as follows: cooking - 23%, restaurant heating system - 19%, water heating (using gas) - 19%, lighting - 11%, other costs - 28%. We examined that saving electricity by 20% will be able to increase the profits by 33%.

The elaboration of proposals to reduce electricity costs in restaurants is given in Table 2.

Table 2 - The elaboration of proposals to reduce electricity costs in restaurants

№	Electricity costs reduction proposal	Saving per year
1	Installation of the motion sensor in the parking lot of a restaurant	Approximately UAH 2000 on one street lamp
2	Photovoltaic cells of the lighting system	Up to UAH 1800 on one refrigerator
3	Fluorescent lamps installation	Up to UAH 500 on 1 light bulb per year
4	Thermostat installation	Up to 30% savings
5	Replace the emergency light bulb with a 20 watt light bulb	Up to UAH 700
6	Make a schedule of those responsible for electrical appliances among employees of the restaurant's production facilities	Up to 10% savings
7	Install a motion sensor or off timer in all service rooms of the restaurant	Up to 15% savings
8	Lighting system modification	Up to 40% savings
9	Replacement of electric stoves with induction ones	Up to 30% of electricity

* systematized by the authors

Resource saving still largely depends on the employees of the restaurant. After all, they should also strive to increase the profits of the restaurant and keep it on the market, because it will not only influence their workplace, but also the amount of wages. It is during a crisis situation that employees are acutely aware of the need for certainty and confidence that management has a plan of action.

In practice, personal contact of the head with the specialists of the restarant is one of the most common ways to reduce uncertainty. Keeping the team regularly informed and assuring it that anti-crisis measures and joint work yield positive results motivate employees to overcome difficulties. The strategy is what the restaurant business will be like after quarantine, whether the establishments will be able to optimize their costs, whether the management system will be flexible and stable enough. Salaries and wages of employees of the restaurant will increase depending on personal qualifications, the number of tasks performed, the quality of their performance. In Ukraine it is advisable to introduce such motivational components (Fig. 5).

In our view, an important factor in achieving a high standard of living, as well as increasing productivity is motivation and incentives. In modern conditions, new models of remuneration are needed, which give space to the development of personal material interest. It is necessary not only to ensure material interest in certain results of work, but also to interest the employee in improving work efficiency.

Nowadays a special anti-crisis policy has become widespread, which includes a significant number of procedural measures to prevent the bankruptcy of restaurants and also procedures to maximize the satisfaction of creditors' claims by debtor companies.

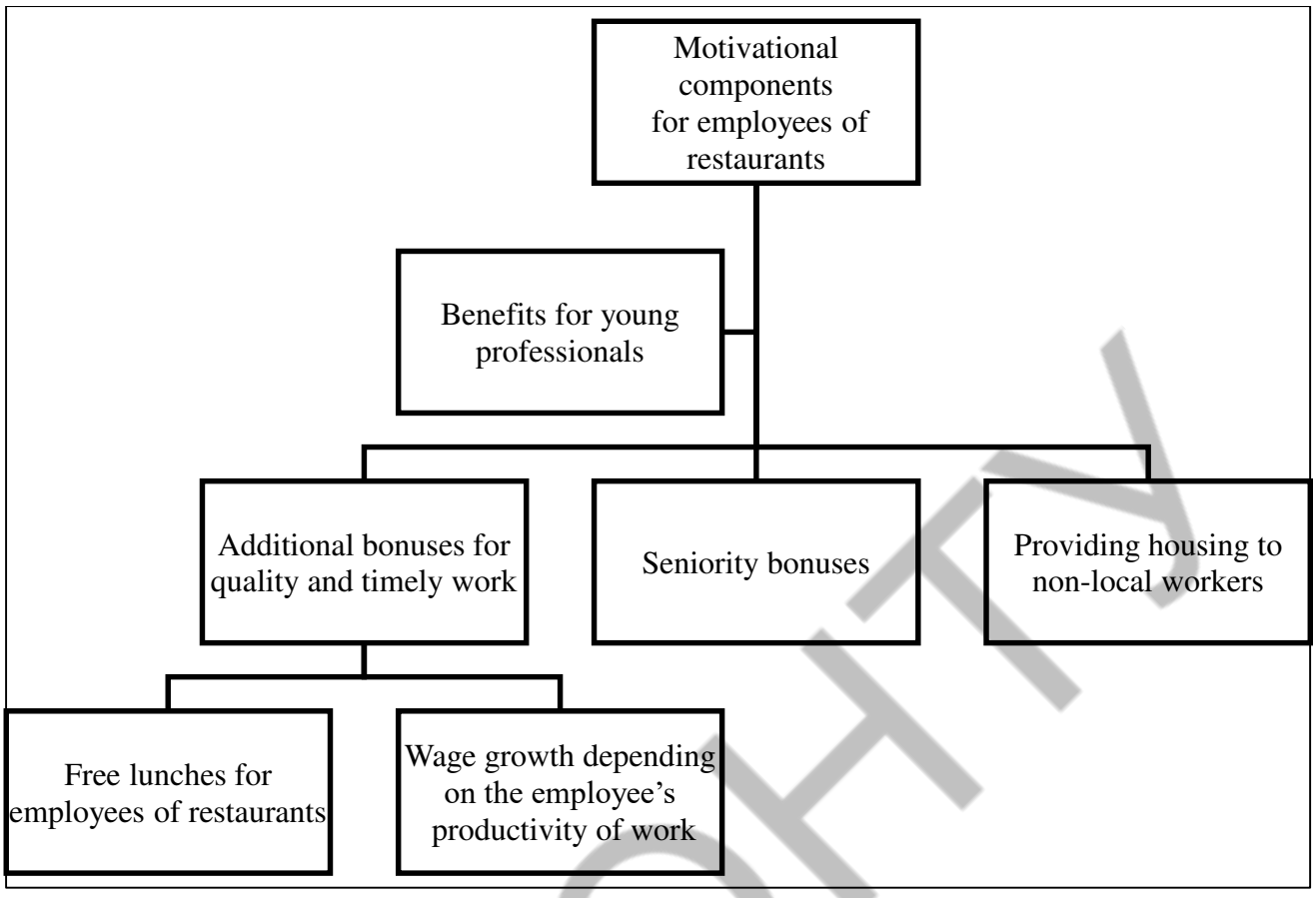


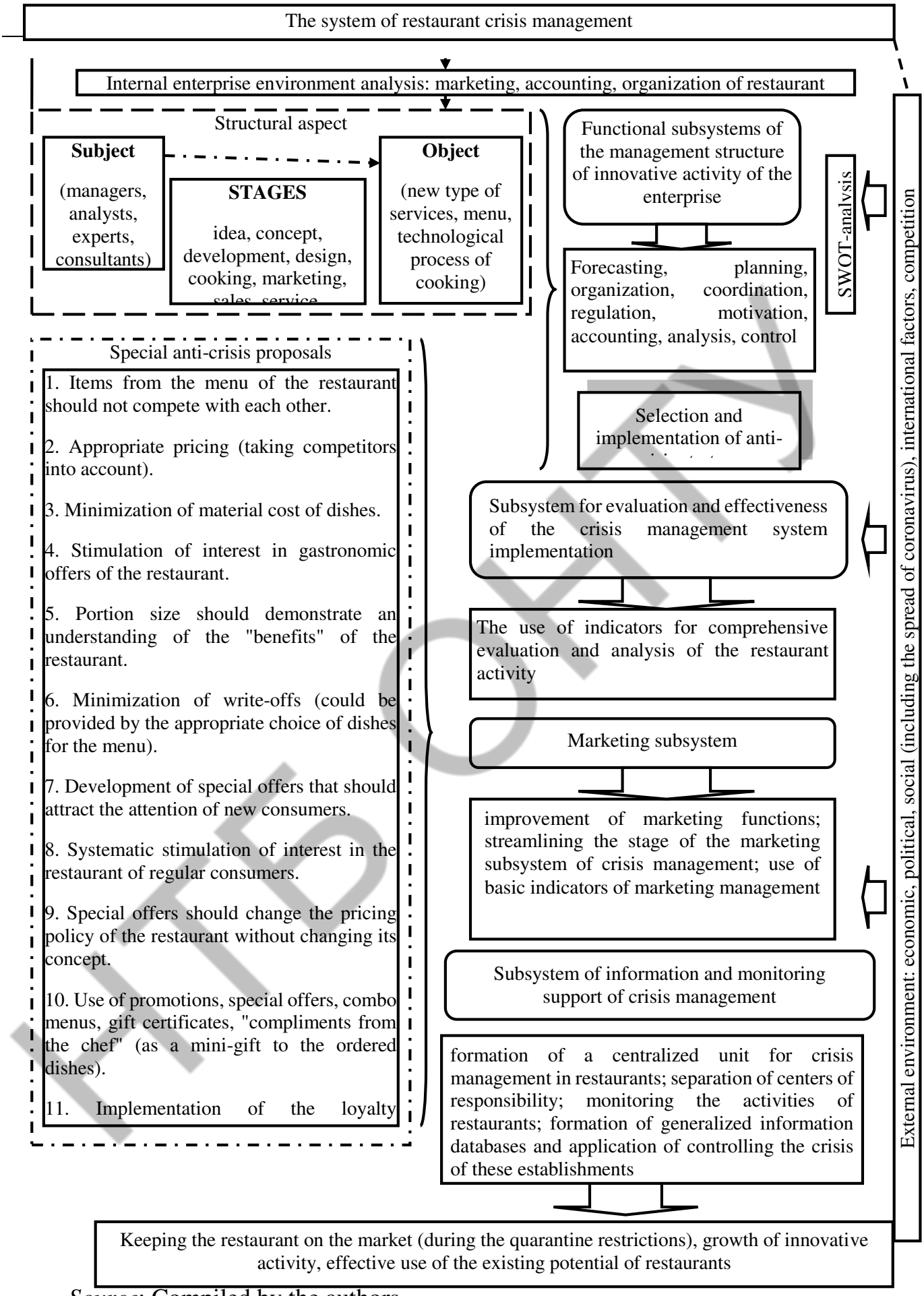
Figure 5 - Motivational components that are recommended for restaurants in a crisis

* Compiled by the authors

The components of the state tools in the system of restaurant crisis management and anti-bankruptcy measures in business activities should be: the availability of effective state support for unprofitable enterprises; influence on the activities of enterprises at the stage of creating a certain business structure; applying control at the state level over certain business transactions; state control over doing business on equal and fair terms; creation of organizations that will develop a methodology for crisis management, provide recommendations and consulting assistance to enterprises in a crisis [2, p. 132].

The structural model of the system of restaurant crisis management is shown in Fig.6.

Thus, as can be seen from Fig.6, an effective way out of the crisis is the use of crisis management procedure, which involves the introduction of production and technical measures into the restaurant activity system, the use of external and internal reserves to restore profitability and avoid bankruptcy.



Source: Compiled by the authors

Financial recovery as an integral part of crisis and bankruptcy management includes a targeted selection of the most effective tools, strategy, tactics needed for a particular type of business. The individuality of the choice of these means does not mean that there are not any generalized means, characteristic of all enterprises in financial crisis. Studying the experience of overcoming crisis situations of both different countries and specific enterprises allows to form a flexible system of crisis management.

The system of restaurant crisis management is a set of coordinated elements that, interacting with each other, diagnose the signs and manifestations of the crisis, help to overcome it and return business structures to stable functioning, create the necessary conditions for overcoming the negative impact of external and internal factors on the establishments activities.

Today, it is difficult to predict the duration of the war, so Ukrainian hotel companies should adapt to new business conditions. It will be appropriate to consider the foreign experience of anti-crisis management of hotel enterprises in the conditions of war. A good example is Israel, which is constantly at war. This country can be a point of reference in research and forecasting of the state of Ukrainian industry and economy. The hotel business sector of Israel organizes its activities taking into account the fact that at any moment there may be processes that will make adjustments to the work of hotels. Today, the country's hotel business is focused not only on transnational chains, but also on small entrepreneurs [10, p.48]. Also, an important component for the functioning of the hotel business in a crisis situation is the activity of the state in financial, tax and other spheres. In Ukraine, during the war, there were also changes aimed at supporting business (table 3).

Table 3 - State support for business during the war

Types of aid	**Essence**
Credit	Deregulation
For business at 0%	Stopped business checks during martial law
The state independently pays interest to the bank	
After the end of martial law, the loan rate will not exceed 5%	
Taxes	Canceled
FOP 1 and 2 groups pay taxes at will	VAT and income tax for businesses with a turnover of up to UAH 10 billion
The state pays EUV for mobilized workers	Payment of environmental tax, minimum tax liability and payment for the land where hostilities took place Businesses with a turnover of up to UAH 10 billion
Pays up to 2% of turnover	

* compiled by the author based on [11]

With the help of state support, various benefits and the crisis management plan personally developed by each hotel, the owners of such businesses manage not to go out of business. However, it is impossible to completely eliminate such losses. The

majority of European tourists, who are used to vacationing at the budget resorts of the Black and Azov Seas and the Carpathian Mountains, could not come this year, and this is a loss of the main income for most hotel enterprises in the resort areas.

V. CONCLUSIONS

As shown above, against the background of the pandemic, the situation of the subjects of economic relations is exacerbated by their unpreparedness for the crisis. Given these points, crisis management is of great importance for market agents, which should be aimed both at preventing the crisis, minimizing its impact, and post-crisis stabilization. Clarification of the place of restaurant crisis management in the theory and practice of management is done through the clarification of the concept of crisis, as well as the factors and causes of its occurrence in the activities of economic entities.

Foreign practice of crisis regulation and the institution of bankruptcy are characterized by an emphasis on communications, innovative and social aspects. Thus, the priority in the process of improving the enterprise condition is to restore the capacity to pay of economic entities, to save jobs. That is why the focus on achieving strategic goals, timely response to "weak signals", innovation policy, adequate state and legislative regulation of bankruptcy and reorganization procedures are especially important in the recovery of restaurant businesses.

In the crisis caused by the coronavirus pandemic, democratic formats and interesting, unique ideas are important, but it is extremely difficult to make any predictions in terms of this crisis - it is not just economic, but systemic, covering basic human values, such as threats to their lives and health. However, the trend towards more affordable restaurants will continue to grow. The experience of other developed countries should be used in creating the new formats of restaurant establishments. It is likely that the fear of a pandemic may persist for a long time and consumers will not return to restaurants in the same numbers as before the quarantine any time soon. On the other hand, in recent years, many people have become accustomed to the fact that it is possible to order almost anything - it's fast, effortless and often not more expensive. The pandemic and crisis are sure to end, so restaurants need to survive this period with minimal losses to be ready not only to reopen to their guests, but also to come up with new interesting projects that will meet their changed values.

Therefore, based on the research of the results of the work of hotel enterprises in the conditions of the war, we can conclude that the hotel business is currently in a state of crisis and effective anti-crisis measures, both on the part of the hotels themselves and on the part of the state, help hotel enterprises to stabilize their activities. It is possible to single out a number of measures that level crisis situations in the hotel industry and help Ukrainian hoteliers, both in the conditions of today and in the process of the post-war period, to restore their business. For example:

1) an important role is played by the support of the state and international organizations through the development and implementation of various programs and projects;

2) carrying out certain actions aimed at supporting the field of hospitality;

3) elimination of interruptions in the supply chain of hotel raw materials for the formation of hotel services and establishment of ways for safe domestic tourism of citizens;

4) focus on the provision of budget services.

In the development of anti-crisis programs for the post-war recovery of the hotel sector, it is also worth taking into account the experience of other countries, whose hotel business operated in similar conditions and suffered losses due to hostilities, in particular war, or crisis situations, but in the near future achieved effective development of the hotel and restaurant industry business.

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TOURIST POTENTIAL OF UKRAINE: CHALLENGES AND PROSPECTS OF THE POST-WAR TIME

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Abstract. *The tourism industry is one of the sectors of the global economy most affected by the pandemic. At the same time, in 2022, having not yet fully recovered from the impact of quarantine restrictions, it was forced to face a completely new challenge for itself - large-scale military operations on a large part of the European territories. It was Ukraine and its tourism sector that suffered the most from the war, and since the prospects for the end of the war are very uncertain, the issue of preserving the country's tourism potential, finding ways to speed up its recovery and post-war development of the tourism sector of Ukraine are gaining particular relevance.*

To substantiate the prospects and challenges for the tourism potential of Ukraine in the post-war period and to determine the key directions of actions of the state and business for its preservation, effective use and expansion during the war period.

The methodological basis of the study was made up of general scientific and special methods of economic theory, in particular, methods of theoretical generalization and comparative analysis and synthesis for the purpose of researching all processes and phenomena of the tourism sector of Ukraine in interdependence and interconnection. In the course of the study, statistical materials of the European Union and Ukraine were applied on the functioning of the tourism sector of the economy and processed using the methods of statistical analysis: comparison, grouping, calculation of average values and proportions, as well as analytical data and assessments of specialized state agencies of Ukraine were used.

A comparison of the impact of the COVID-19 pandemic on the development of the tourism sector of Ukraine and individual EU countries and the shares of tourism trade turnover in their GDP is made, which has revealed to note the low level of use of Ukraine's own tourism potential in the pre-war period. The key strengths and weaknesses of the tourism sector of Ukraine according to the version of the World Economic Forum have been studied and the prospects and consequences for them as a result of the war have been substantiated. A number of strategic courses of action for the state and business are proposed, based on the main possible prospects for the duration of active hostilities.

Keywords: *tourism sphere, tourism potential, Ukraine, war, post-war recovery, prospects, challenges, development.*

I. INTRODUCTION

The tourism industry is one of the sectors of the global economy that has been most affected by the pandemic. At the same time, in 2022, having not yet fully recovered from the impact of quarantine restrictions, it was forced to face a completely new challenge for itself - large-scale military operations on a large part of the European territories. Thus, the active growth of indicators of global turnover in the field of tourism at the beginning of this year came to a sudden halt at the end of February, and not even so much because of the actual hostilities on the territory of our country, but because of the uncertainty of the nearest prospects for economic development and sanctions restrictions on the aggressor country and its satellite. It is clear that the key purpose of the imposed international sanctions is to weaken the Russian economy as much as possible, but at the same time, they also have a significant impact on the economies of the countries that impose them. According to analysts' forecasts [1; 2], it is the economy of the developed countries, and in particular, the countries of the European Union, that will suffer the most from the war in Ukraine, of course with the exception of Ukraine itself.

The main consequences of the sanctions, primarily for the European countries, have been the increase in the price of fuel and energy resources and, as a result, the increase in prices for almost all types of products and services, which could not but bypass services in the field of tourism business, affecting both incoming and outcoming tourist flows. This, in turn, has forced international organizations to even revise their previous forecasts regarding the recovery of the industry - so, according to the Organization for Economic Cooperation and Development, the full recovery of international tourism at the pre-pandemic level should be expected no earlier than 2025 [3].

II. THE LITERATURE REVIEW

International and regional organizations, national structures and associations, as well as a number of researchers whose works are relevant for certain countries, regions, etc., have been paying considerable attention to the study of the problems and prospects of the tourism business, especially since the global manifestation of the consequences of the COVID -19 pandemic.

Domestic scientists also do not ignore the problem of the functioning of the tourist business during the war and the ways and possibilities of its post-war recovery. In particular, A. Motsa , S. Shevchuk and N. Sereda [4] propose to refer to the experience of the post-conflict restoration of tourism in Croatia and Cyprus, but do not take into account the fact that in both studied countries there were precisely civil conflicts without the use of that excess of extremely destructive artillery and missile projectiles that is currently taking place in Ukraine, without large-scale destruction of civilian infrastructure and extreme damage to the environment.

Another team of scientists [5], having analyzed the tourism sector of Ukraine under martial law, comes to a conclusion regarding the need to form a strategy for the post-war recovery of Ukraine and the development of tourism in places of military glory. The opinion regarding the need to develop military tourism is supported by M. and N. Barvinok [6; 7], who, in their research, focuse on attempts to assess the lost tourist and recreational potential of the country as a result of the occupation of territories and full-scale hostilities, destruction and theft of the national cultural and

artistic heritage, etc., and on the study of the possibilities for restoring the country's tourism industry at the expense of military tourism in the post-war years. Some authors [8] conducted a study of views on the relationship between war and tourism, especially in the context of evaluating and analyzing the possibilities of the development of the tourism sector in the conditions of terrorist or military threats.

Highlighting previously unsolved parts of the general problem, to which the article is devoted. The question of the post-war development of the tourism sphere of Ukraine and the search for ways of its accelerated recovery are currently in the field of view of a significant number of scientists. However, at the same time, the available studies are somewhat narrowly focused and do not offer a comprehensive examination of the challenges and prospects for the domestic tourism business in the post-war period.

III. THE SUBJECT OF THE STUDY, RESEARCH METHODOLOGY

Formulation of the goals of the article (statement of the task). The purpose of the study is to substantiate the prospects and challenges for the tourism potential of Ukraine in the post-war period and to determine the key directions of state and business actions for its preservation, effective use and expansion during the war.

The methodological basis of the research is made up of general scientific and special methods of economic theory, in particular, methods of theoretical generalization and comparative analysis and synthesis with the aim of researching all processes and phenomena of the tourism sector of Ukraine in interdependence and interconnection. In the course of the study, statistical materials of the European Union and Ukraine on the functioning of the tourism sector of the economy are applied and processed using the methods of statistical analysis: comparison, grouping, calculation of average values and proportions, as well as analytical data and assessments of specialized state agencies of Ukraine are used.

IV. THE RESULTS OF THE STUDY

The tourism sector of Ukraine during the period of total quarantine restrictions was characterized by similar trends to the group of countries of the European Union, connected by decades of common economic space in the past (Table 1).

Table 1

Quarterly indicators of relative changes in turnover in the field of tourism in Ukraine and individual EU countries in 2020–2021 (to the same period of the previous year)

Country	2020				2021			
	Q I	Q II	Q III	Q IV	Q I	Q II	Q III	Q IV
Ukraine	-2.95	-58.4	-40.9	-40.7	49.8	138.3	84.6	57.6
Bulgaria	-23.2	-94.5	-69.3	-72.3	-54.2	576.9	155.6	128.9
Czechia	-20.2	-93.9	-82.6	-83.1	-66.9	381.3	172	261.2
Estonia	-21.4	-82.8	-83.8	-84	-74.2	106.7	231.2	306.8
Latvia	-15.1	-81.6	-69.1	-70.9	-60.2	140.9	92.4	136.6
Lithuania	-24.1	-94.8	-87.7	-83.5	-63.4	537	353.1	305.7
Hungary	-38.8	-85.3	-81.4	-88.7	-67.8	42.2	112.2	358.2
Romania	-12.7	-79.4	-50.6	-58.9	-41.8	197.5	49.3	123.9

Source: built and calculated by the author according to data [9; 10]

However, despite the similarity of trends, the calculated indicators allow us to note clear differences. Thus, the domestic tourism sector lost significantly less as a result of COVID-19, recording a loss of a maximum of 60% of turnover in Quarter II of 2020 compared to the same period of the previous year. In contrast, other countries of the post-socialist camp in the same period recorded a drop from 80% in Romania to 95% in Lithuania and Bulgaria.

The recovery of tourist activity in Ukraine also began earlier than in other studied countries - according to the results of the first quarter of 2021, the domestic tourism business recorded an almost 50 percent increase in turnover. On the other hand, in the studied countries of the European Union, business continued to reduce indicators of tourism turnover. It should be noted that although the recovery of the tourism sector in the studied EU countries began later than in Ukraine, it was characterized by significantly higher rates of growth.

It should be pointed out that, compared to the studied countries, the share of the contribution of the domestic tourism business to the gross domestic product is extremely low (Fig. 1).

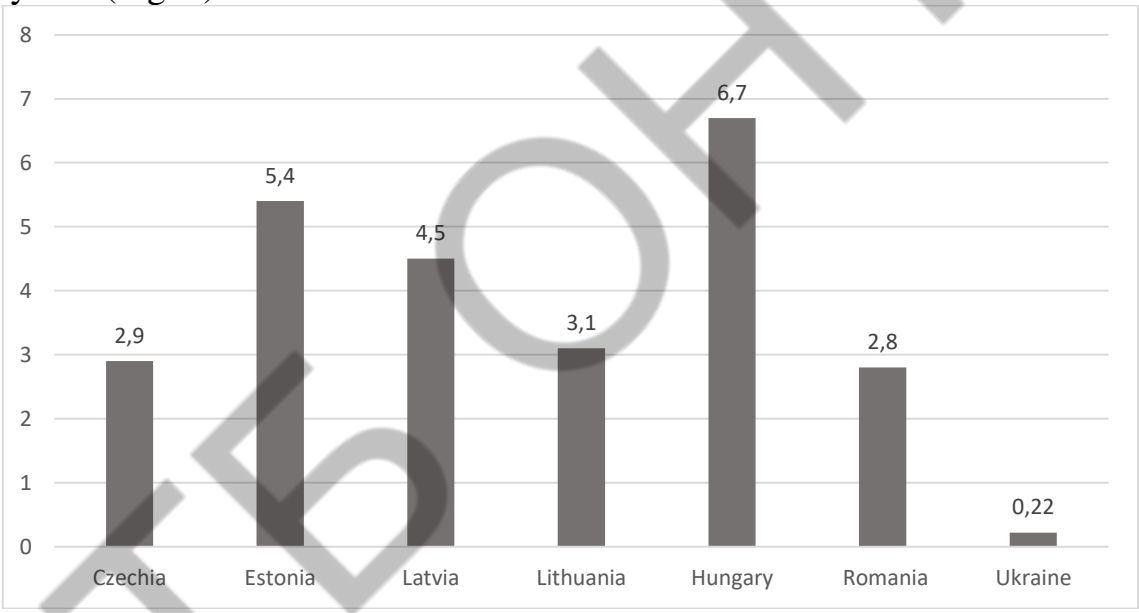

Figure 1. The share of the country's tourism turnover in its GDP (average value for 2019–2021), %

Source: calculated by the author according to data [9; 11]

In fact, with the extraordinary beauty and tourist value of the territory, the majestic culture and a significant number of historical and artistic monuments, Ukraine almost does not use the existing tourist potential, especially in comparison with the studied countries of the post-socialist space. Thus, the tourism business forms only 0.22% of the domestic gross domestic product product, while in neighboring Romania and Hungary – 2.8 and 6.7%, respectively.

It is worth noting that at the beginning of 2022, the tourism sector of Ukraine became noticeably more active, showing a significant increase in the volume of activity, however, a full-scale military invasion completely destroyed all the hopes of business representatives in the field of tourism. At the same time, in just a few months of full-scale war - as of June 13, 2022 - the damage caused to the sphere of culture and

tourism was estimated at 0.7 billion dollars [12]. Therefore, from our point of view, the evaluation of the possibilities of using and increasing the tourism potential of Ukraine in the context of the prospects and challenges of the post-war period should be carried out taking into account both the state and trends of pre-war development and post-war consequences.

In order to understand the existing strengths and weaknesses of the pre-war tourism potential of our state in comparison with the nearest neighbors - the countries of Western Europe, we used the indicators of the World Economic Forum as part of the assessment of the Tourism and Travel Index (Fig. 2).

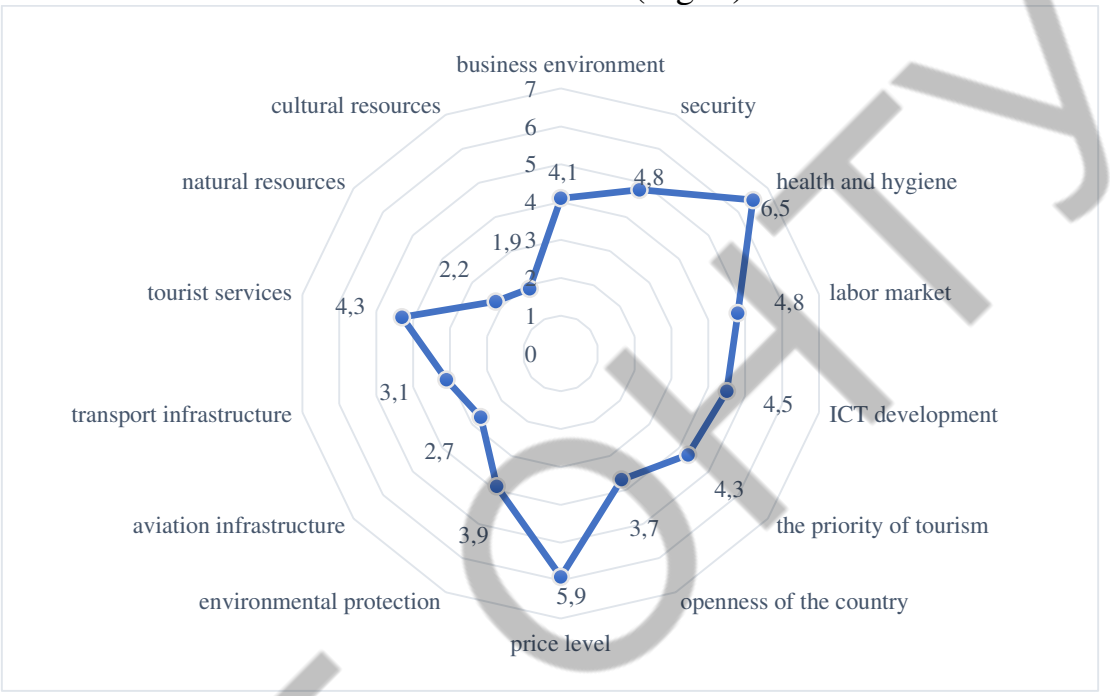

Figure 2. The consequences of the COVID-19 pandemic for the Ukrainian tourism

Source: built on the basis of [13]

Therefore, the biggest weaknesses of the tourism sector of Ukraine are air infrastructure, as well as natural and cultural resources. As for the aviation infrastructure, this is one of the most problematic aspects of the post-war recovery of the domestic tourism sector. Firstly, at the moment, the total amount of damage to the aviation industry of Ukraine is already estimated at 57.3 billion hryvnias (airports and aviation equipment) [12], and secondly, the forced stoppage of air transport activities leads to personnel losses in the industry, which will also be impossible to quickly fill in the post-war period. This situation is particularly negative in the context of the fact that 63% of inbound tourists arrived in Ukraine by airliners [14].

With regard to natural and cultural resources, in this aspect, it is worth noting the peculiarities of the applied assessment methodology, according to which the number of objects included in the world natural and cultural heritage of UNESCO and the share of protected natural territories (national parks, nature reserves, etc.) are taken into account. Taking into account the fact that as of the end of 2021, there were only 7 such objects in Ukraine (0.6% of the global number), of which only 4 are located entirely on the territory of the state [15]. According to such an assessment approach,

our country has little chance of getting higher scores according to the indicated indicators. Even taking into account the possibility of including 17 more objects on the UNESCO list, which are currently on the preliminary list, Ukraine will not be able to significantly increase the score on the parameter of natural resources.

In addition, according to the parameter of cultural resources, the authors of the index evaluate the share of international business meetings (summits, forums, meetings of international organizations, etc.) in each country, which, taking into account the rather ill-conceived international communications of the Ukrainian authorities for several years before the large-scale invasion and transformation of Ukraine from subject into an object of international policy, did not give chances for obtaining higher points according to the specified parameter.

On the other hand, the strengths of the domestic tourism sector include the level of development of tourist services and tourist infrastructure, the level of prices, as well as indicators of the development of hygiene and the health care sector - the ability to provide qualified medical assistance to tourists in case of need. Since the possibility of infection with infectious diseases is taken into account in the parameter of health care, the significant spread of COVID-19 affected their importance around the world, and Ukraine was no exception.

Thus, before the start of a full-scale war on the territory of Ukraine, its tourism sector was characterized by a fairly high level of competitiveness in terms of price level parameters, development of tourist infrastructure and health and hygiene among Western European countries, although in other parameters it was significantly behind in development. Nevertheless, according to a survey conducted by the State Agency for Tourism Development (SATD) at the end of 2021 [14], 29% of incoming tourists chose Ukraine for vacation, recreation and leisure.

Another important point in matters of the post-war restoration of the tourism potential of Ukraine is the fact that since the beginning of the full-scale military aggression, objects of the cultural and tourist sphere from 14 oblasts have been damaged [14], among which Dniprovsk, Donetsk, Zhytomyr, Zaporizhia, Kyiv, Luhansk, Mykolaiv, Odesa, Sumy, Kharkiv, Kherson and Chernihiv should be included as the most affected regions. At the same time, about 30% of the territory of Ukraine - precisely within the limits of the specified regions - is mined, according to the notification of the State Emergency Service [16], which automatically makes them dangerous for many years of the post-war period, and this is, in fact, the entire sea coast of the country, which, at least, excludes the possibility of a full restoration of beach tourism in the coming post-war season.

On the other hand, the regions whose tourism facilities were practically or not at all damaged have been able to maintain the vital activity of the tourism sphere and even quite successfully: taking into account the situation that developed in the country in 2022, tourism enterprises made only 18% less of tax payments to the budget compared to the previous year [17]. It is clear that such a situation has occurred mainly due to the forced relocation of a significant number of Ukrainians from the regions of hostilities, however, domestic tourism has not stopped functioning.

Consequently, currently Ukraine has quite high prospects for the post-war restoration of inbound tourism, at least to tourist regions bordering the European

countries, and at most to the north-western and central regions. However, it is possible provided that further active hostilities and destruction of tourist facilities will not spread to the specified territories. At the same time, it should be stated that prolonging the war for years will only deepen the crisis in the tourism sector and will delay the prospects of restoring Ukraine's former tourism potential, not to mention its expansion.

Thus, today it is necessary to develop at least two possible strategic options for the further functioning of the business both at the level of the state and at the level of operating enterprises of the tourism sector, based on the following considerations:

- the active phase of the war will last until the end of 2023 at most;
- the war will develop into a long, multi-year conflict with periodic reductions in hostilities.

In the first case, when developing strategic development plans, one should focus on the advantages that Ukraine currently has - extremely wide representation in the world mass media, support of key public figures and celebrities, growing interest in Ukraine and admiration of the Ukrainian people, etc. in order to use all available information sources and platforms for reporting on places of interest, cultural and artistic objects and achievements, to popularize tourist Ukraine.

An important aspect of the work in this direction should be the improvement of the infrastructure of the border regions bordering the EU countries. And we are not only talking about the quality of roads and the availability of related infrastructure - gas stations, food and accommodation facilities that are sufficient in the western regions, but primarily about ensuring the uninterrupted supply of electricity to checkpoints to avoid the formation of queues when crossing the border. The speed of crossing the border is a key condition for the development of automobile inbound tourism from the European countries.

Based on the assumption that the war in Ukraine will not end during the next year and will develop into a protracted conflict, the main task of the state in the context of, if not development, then at least supporting the vitality of the tourism sector will consist in the formation of clear criteria for safe tourism, the formation of interactive multilingual maps with interesting routes through conditionally safe regions and locations, marked areas of shelters, points of uninterrupted power supply and facilities and institutions capable of functioning in blackout conditions. The higher quality and more functional their content, the higher the chances of attracting the interest of a foreign tourist.

As for the business entities of the tourism sphere of Ukraine, the most critical protracted war will be precisely for travel agencies. A further decline in the level of the population’s ability to pay and significant restrictions on the departure of men abroad will further reduce the demand for outbound tourism. Under these conditions, those economic entities that can arrange appropriate shelters, create conditions for autonomous power supply of the institution (object) in blackout conditions, provide interesting, extraordinary experiences and routes, etc. - will be able to attract and serve both foreign tourists and internal organized tours.

However, business operating in the field of rural tourism will receive significant prospects for development. The high level of stress and tension actualized the desire of Ukrainians to rest away from big cities and systematic air alarms. Therefore, the

intensification of efforts in the direction of improving rural tour products, aimed at combining differentiated offers aimed at satisfying the most important needs for consumers, can become a key driver of the active development of rural tourism in Ukraine during the war, and in the future, that is, in the post-war period, even take a significant share of the country's tourism market.

V. CONCLUSIONS

Ukraine's tourism potential is extremely significant, although it has been far from fully utilized before the full-scale invasion due to various reasons. Fighting on the territory of the country and large-scale destruction, including objects of cultural and artistic heritage and tourism, have caused significant damage to the tourism sector of only certain regions, while in the vast majority of regions of the country, primarily critical and transport infrastructure have been affected.

The greatest challenge to the tourism sector at the moment is the uncertainty regarding the duration of the war and its final consequences. This requires the search for possible options for strategic decisions both for the state and for individual subjects of the country's tourism sphere, aimed at ensuring the preservation and maximum effective use of the tourist potential for each variant of the development of the situation. In any case, only complex interaction and joint efforts of the state, local self-government bodies and representatives of the tourism business will help to overcome the challenges, preserve the country's tourism sector during the war and ensure its rapid recovery after its end.

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POSITIVE PSYCHOLOGY AND TOURISM

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Abstract. *In recent years, tourism and positive psychology has developed as a humanist-inspired study of individual flourishing in tourism. In this context, psychology and tourism are a successful partnership to develop meaningful experiences considering tourists' needs, desires, and expectations. This interconnection is observed through the application of positive psychology in the context of meaningful tourist experiences. This approach comprises adequate indicators to explore the tourism field from the perspective of individuals' well-being. Positive psychology, positive tourism, well-being, and mindfulness constitute the theoretical foundations of this scientific paper, which intends to understand how they are intertwined to fulfil one goal: developing meaningful tourist experiences. This scientific paper offers a theoretical reflection on the connections between the referred theoretical foundations. Suggestions are also made to further expand the traditional focus on tourist behavior to include the well-being of host communities and tourism workers.*

Keywords: *happiness, well-being, positive psychology, meaningful experiences, mindfulness, positive tourism.*

I. INTRODUCTION

According to the International Recommendations for Tourism Statistics 2008 (Department of Economic and Social Affairs – Statistical Division [DESA], tourism is a social, cultural and economic occurrence that refers to the movement of people to somewhere different from their normal residence, with a crucial influence on the economy, environment, locals' lives and the tourists themselves. [1] DESA classifies tourism trips in two major categories: personal and professional. The personal includes: a) holiday; b) leisure and recreation; c) visiting friends and relatives; d) education and training; e) health and medical care; f) religion/pilgrimage; g) shopping; h) transit; and i) other. [1]

The European Travel Commission [ETC] [2] believes that in the near future travel and tourism business will be intensely affected by the tourist's needs to better his/herself and to live a more fulfilled life. Tourism is a way to improve life [3] and for Zhang [4] it is an activity intimately connected to wellbeing, which in turn is the search for a greater quality of leisure life when people basic needs are fulfilled.

Wellbeing is potentially a strong marketing instrument affecting consumer decision [5]. If a good strategy is put in place and if consumers start to understand the significance of a healthy lifestyle, there will be more motivation to travel to destinations that promote positive outcomes for people's wellbeing [5].

A well-conceived travel experience is crucial for the development of a sustainable tourism strategy [6].

Researchers are now considering that there is a merging between Positive Psychology and Tourism Psychology that can lead to the development of positive changes and enhance psychological wellbeing. Our goal with this systematic literature review is to develop an overview of the relationship between Positive Psychology and Tourism, and its application in the sector [7].

II. LITERATURE ANALYSIS

Currently, research focused on human flourishing is allowing for the emergence of different directions in a specific field, namely tourism. Investigations surrounding tourist's learning, relationships and even empathy regarding host communities are already being conducted [8].

Having Seligman's theory as a support, Filep and Deery [9] advocated that tourist happiness "is a state when a tourist experiences positive emotions (such as love, interest, joy, contentment), a sense of engagement in an activity (like flow or mindfulness) and derives meaning from tourist activities (or a sense of greater purpose)" [10]. The happiness model for tourist satisfaction is associated with the 'quality of life' construct and tourism can be seen as a significant element to promote quality of life of the tourists [11]. Uysal, Sirgy, Woo and Kim [12] explained that researchers tend to use 'quality of life' and 'wellbeing' indifferently, and tourists' quality of life is influenced by touristic activities and experiences. Overall, research [12] leads us to believe that tourism influences the tourists' quality of life, generating a positive effect on leisure, social, family, work, spiritual, culinary, marital, cultural and many more aspects [7].

Coghlan [6] concluded that Positive Psychology principles are a valuable tool to develop experiences for tourists that promote mental health, such as charity challenge events. Kruger [13] found that, in a particular setting of tourism event, it was the features of the event *per se* and the development of relationships that most increased the visitors' life satisfaction and happiness. Filep [14] argued that to conceptualize tourist happiness in terms of subjective wellbeing is difficult since a) it is hard to explain meaningful holiday experiences through it and b) it cannot clearly explain people's engagement with local experiences. For Filep [14] the authentic happiness model is more accurate to explain tourist happiness.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

The object of the study is the interrelationships between positive psychology, positive tourism, well-being and awareness regarding the development of a meaningful tourist experience.

The subject of the research is the theoretical, methodological, organizational and practical aspects of the functioning and interaction of positive psychology and tourism

The research methods are comparison, explanation, abstraction, empirical analysis and synthesis, a combined method of similarity and divergence.

IV. RESULTS

4.1. Positive Psychology

Positive psychology is one of the newest branches of psychology to emerge. This particular area of psychology focuses on how to help human beings prosper and lead healthy, happy lives. While many other branches of psychology tend to focus on dysfunction and abnormal behavior, positive psychology is centered on helping people become happier [15].

Positive psychology is designed to "complement and extend the problem-focused psychology that has been dominant for decades," explained the late Christopher Peterson, author of "A Primer in Positive Psychology" and professor at the University of Michigan, in a 2008 article published in *Psychology Today [15]*.

"Positive psychology is...a call for psychological science and practice to be as concerned with strength as with weakness; as interested in building the best things in life as in repairing the worst; and as concerned with making the lives of normal people fulfilling as with healing pathology," Peterson wrote [15].

According to leading authorities in the field, Martin Seligman and Mihaly Csikszentmihalyi, positive psychology will help achieve "scientific understanding and effective interventions to build thriving in individuals, families, and communities."[15]

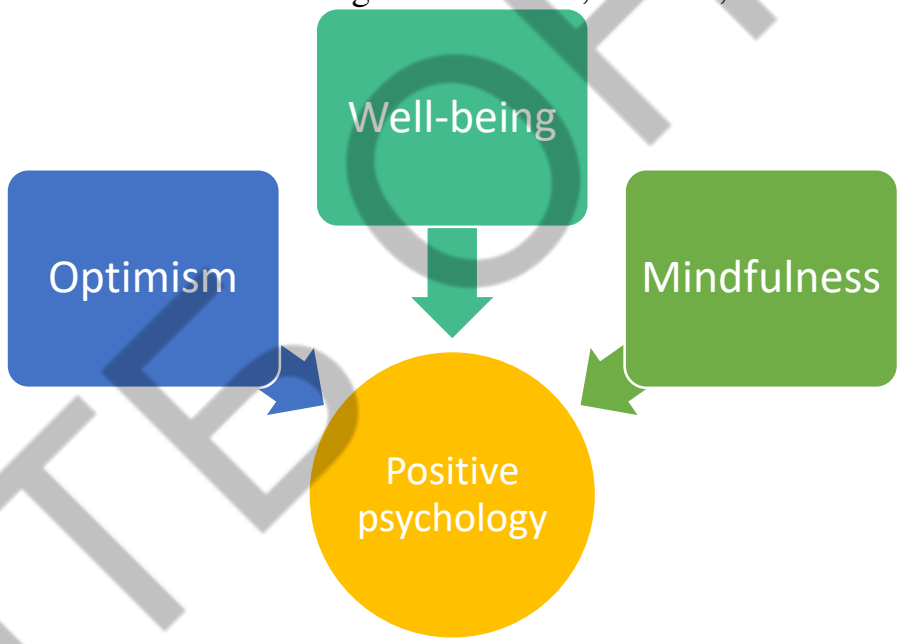

Fig. 1. Components of positive psychology

The philosophical roots of positive psychology can be traced back to Ancient Greece, such as the writings of Aristotle on happiness and the good life. This was used as the foundation to establish the roots of psychology in the 20th century, leading fi rst to humanistic psychology and later to positive psychology. Positive psychology is simply considered as 'the study of what makes life worth living' [16], which includes a broad focus on health, leisure and recreation, including sports, tourism, and well-being[17].

In addition to these early roots, work in this field also builds on psychological traditions in psychoanalysis, behaviorism, cognitive therapy and existential psychology that contributed to initial understandings of positive dimensions of human

existence [18].The work of Freud [19] on the pleasure principle, Jung's [20] ideas on spiritual and personal wholeness, Frankl's [21] work on finding meaning under dire human conditions, and Adler's [22] discussions of healthy individual strivings motivated by social interest have all facilitated the development of a contemporary positive psychology scholarship.

Maslow's [23] work on human needs, self-actualization, and fulfillment is especially seminal in the foundations of positive psychology, as Maslow himself introduced the term positive psychology to his readers. According to the hierarchy of needs – which begins at the bottom of a pyramid and stretches to the top – in order to make life worth living people need to partially or fully satisfy their varying needs, including physical (e.g. safety, security, hunger) and psychological (e.g. love, respect, self-esteem, aesthetic) needs. The accumulation of these out-comes refers to self-actualisation (at the top of the model pyramid). The degree of infl uence of such needs varies based on a person's expectations, which result from their social, economic and psychological background [17].

As a movement of perseverance, strength, and virtues, positive psychology encourages individuals to overcome challenges and develop a sense of independence that will lead to self-sufficiency and, thus, to compete for a sense of reward and independence [24].

Peterson and Seligman [25] established the existence of six cross-cultural virtues, each one with their strengths (in parentheses): (1) wisdom and knowledge (creativity, curiosity, open-mindedness, love of learning, perspective), (2) courage (bravery, persistence, integrity, vitality), (3) humanity (love, kindness, social intelligence), (4) justice (citizenship, fairness, leadership), (5) temperance (forgiveness, modesty, prudence, self-regulation), (6) transcendence (appreciation of beauty and excellence, gratitude, hope, humour, spirituality).

Positive psychology has three pillars: (1) positive emotions, placed in time, as a *continuum*; from this perspective, positive emotions related to the past (e.g. satisfaction, contentment, fulfilment, pride, serenity), present (e.g. joy, ecstasy, calm, zest, ebullience, pleasure, flow, happiness), and future (optimism, hope, faith, trust); (2) positive individual traits, like subjective well-being, optimism, happiness, and self-determination [26]; and (3) positive institutions, like responsibility, nurturance, altruism, civility, moderation, tolerance, and work ethic [27].

Positive psychology is often confused with positive thinking, and misconstrued as self-help tactics rather than research-backed theories. Positive thinking is a way of thinking ourselves into better behavior and greater resilience, rather than behaving our way into a different frame of mind [15].

Positive psychology, on the other hand, is the scientific study of what makes people thrive. It focuses on behaviors that can lead to a more optimized frame of mind as well as on thought patterns that lead to more functional behaviors [15].

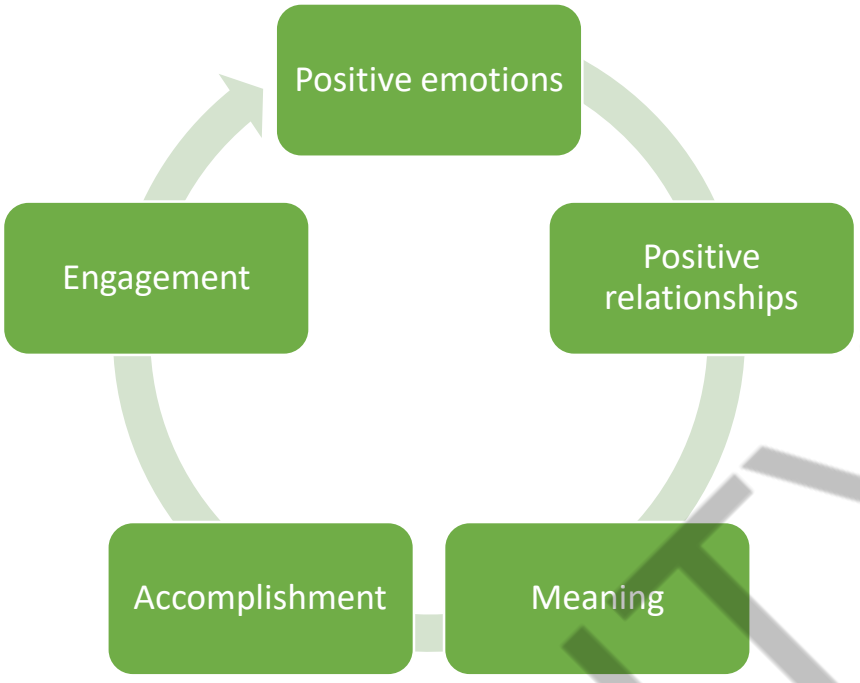

Fig. 1. The most common model underlying a positive tourist experience

Positive psychology's mission is to understand the factors that lead individuals, communities, and societies to flourish.

One of the contexts in which positive psychology has been applied is tourism [16,7]. Travelling is an experience that since the beginning has had a strong meaning attached to it: it starts with the recognition of the need to satisfy something that is currently missing, the development of expectations, and destination choice (anticipation phase, the tourist experience itself, where individuals develop emotions, meanings, feelings, and memories [on-site phase], and the evaluation of the experience [reflexive phase] [28].

One of the first attempts to join positive psychology and tourism was suggested by Filep [10], with the proposal of a subfield called positive tourism.

4.2. Positive psychology and positive тourism

Positive tourism focuses on the hedonic and eudaemonic human well-being components, with the primary objective being to understand tourists', local communities', and tourism workers' flourishing, depending on the characteristics of meaningful tourist experiences, the relationship between tourists and the local community, and the kind of interactions between tourism industries and tourists, aiming to promote well-being through three pillars: (1) *positive tourism experiences*, which offer opportunities for social interactions, personal growth, identity development, and reflection on the purpose of life [24]; (2) *positive host communities*, characterised by emotional commitment, feelings of moral obligation, interest in the welfare of others, and reduced uncertainty about the other's likely behaviour [24]; (3) *positive tourism workers*, responsible for emotional engagement with clients, guiding roles that mediate experiences and facilitate life changes that help tourists achieve their

goals, grow, and develop themselves. In turn, this provides tourism workers with a sense of meaning in life by transforming other peoples' lives [29].

Positive tourism is related to well-being, as both focus on the development of *positive relationships* between individuals and the visited place, competing to develop meaningful experiences [16, 7,30]. Both positive tourism and well-being focus on the *social component* of meaningful experiences, a topic that can dictate the success or lack thereof of the experiences on account of the critical role that the host communities and tourism workers play in promoting their destinations as meaningful [16].

4.3. Positive psychology and the PERMA Model

In order to better explain and define well-being, which is a primary focus in positive psychology, Seligman created the PERMA model. PERMA is an acronym for the following five elements of well-being:

- **P**ositive emotions, or experiencing optimism as well as gratitude about your past, contentment in the present, and hope for the future
- **E**ngagement, or achieving "flow" with enjoyable activities and hobbies
- **R**elationship, or forming social connections with family and friends
- **M**eaning, or finding a purpose in life larger than you
- **A**ccomplishments, or goals and successes[15].

Each of these elements is pursued by individuals, contributing to the overall experience of well-being [30]. As Filep acknowledged, the outcomes of PERMA have been projected onto tourism experiences in different phases of the trip. Filep and Deery considered that positive emotions could reach higher values when individuals imagine their travel, namely what they expect to find based on information searched or received through the advice of someone. This process promotes a more robust engagement with the travel experience and the development of meaning and purpose.

4.4. Authenticity and the tourist's search for Being

One of the main reason people travel abroad is to enjoy an "authentic" experience. They imagine travelling abroad and living in accommodation which is slightly different, tasting unique cuisines and participating in local activities while absorbing diverse cultures. Tourists generally seek an authentic experience in which they can go beyond what Maslow termed 'selfactualization' and in fact discover a true sense of Being. Recognizing the great importance of authenticity is an opportunity for Africa's tourism industry and the desire of tourists to 'find themselves' by linking with authentic heritage, cultures and traditions presents huge opportunities for especially local communities. Tourists are not impressed by inauthentic pseudo sites and objects and tourism offerings and such like, and will travel to destinations that offer authenticity [32].

Tourism can be a powerful tool of development, but its potential can also be wasted. Too often tourism enterprises see each other only as competitors and end up frustrating visitors. Every destination talks about quality and exceeding visitors' expectations, but what is the spark that transforms a destination into something

remarkable? It is the destination that has pride in itself and its people and is passionate about celebrating its heritage, its food, its landscapes and its people. Of course, authenticity does not guarantee sustainability, but without the celebration of ‘‘local distinctiveness’’ it is just ‘‘another resort’’. Carey [32].

Wilmott and Nelson identify the intricacy of consumerism, with tourists as important consumers who are seeking new meaning in their lives, which is in line with Maslow’s selfactualization concept. In fact, many tourists seek far more. While there is huge global poverty, there is also a huge global accumulation of wealth [32].

This means that tourists are seeking self-esteem and self-actualization because they recognize that they possess all that they require materially speaking. They thus spend large amounts of money on tourism services through which they hope to improve their lives and arrive at a sense of Being which they feel may be lacking. Tourists desire new experiences which are truly authentic and meaningful and in which they can discover their sense of Being. This is evident by, for example, the numbers of people travelling to interalia, game parks in Africa and the ruins of the Acropolis in Athens. Travelling domestically or abroad is considered a luxury experience and those who embark on such ventures have identified an authentic cultural experience as being the most important aspect and this applies across all age, gender and socio-demographic groupings. The authentic experience is especially about avoiding areas and activities where there are multitudes of other tourists, and suggests that tourists desire to explore the untouched and unexposed [32].Research conducted by the Future Foundation, has uncovered that expensive holidays in faraway places are now viewed by consumers as the most important experience [32].

Tourists seek to experience some relief from the mundane and exhausting daily activities which often threaten to overtake their lives. Consequently many travel to escape and find themselves as they recapture a sense of authenticity (Pearce and Moscardo 1986). Tourism is a sign of wealth and even status and of course it is critical in national economies and all nations seek to bolster tourism so as to obtain much needed foreign exchange but what is it that tourists seek? [32].

Generally tourists travel to exotic and far-flung destinations so as to seek out novel experiences and different ways of life. This gives a sense of worth and value to them and especially to those who are affluent since they are able to flaunt their achievement. They generally seek an authentic experience. and vigorously seek authentic experiences, during their holidays, so that they are able to return to their homes having experienced first-hand an unconventional or primitive lifestyle that is linked to history in some or other way [32].

4.5. Mindfulness

Mindfulness has been defined as a state of mind where individuals experience strong attention to and awareness of what happens in the moment, which gives individuals the opportunity to be implicitly aware of the context and content of the information, notice new details, and feel sensitive to context. Considered the consciousness property with the highest relation to well-being, mindfulness involves an openness to novelty, self-acknowledgement, and self-regulation, helping individuals

be conscious of awareness through scanning the physical sensations of the body, thoughts, feelings, or emotions and by exploring what surrounds them [7].

Dutt and Ninov studied the role of mindfulness in helping tourists remember the interactions established within tourism businesses. The results confirmed that mindfulness influenced tourists' positive memories through unique experiences, features, variety of facilities, and services offered, showing the strong potential of this movement to impact tourists' memories about the destination. The framework divided the factors involved in this process into individual (interest, perception and mindset, people, and interpersonal relationships) and site factors (people and interpersonal relationships, experience, aesthetics, safety, and control) and the benefits into hard (word of mouth, satisfaction), and soft benefits (understanding, history, culture and heritage, environment, difference, and infrastructure) [7].

Mindfulness theory from applied social psychology has been used in tourism research for understanding tourist behaviour, and the nature of tourist experience. The aim of applying mindfulness theory in examining tourist experience has been to enhance effective interpretation or communication among tourists, tourism settings and hosts [33]. Mindfulness theory adopts a cognitive dual information-processing model based on opposite mental states of mindfulness or mindlessness [33]. This model considers a mindful tourist is more attentive to what they are doing and learning, while a mindless tourist responds in an automatic manner and does not distinguish novel stimuli as readily. Therefore, improving the mindfulness quality of an interpretative material increases its effectiveness. Tourism research in this area has focussed on the effect of interpretive learning on tourist satisfaction in settings such as museums or national parks. The concept has also been applied to tourist precincts such as shopping villages [33]. In museums, mindfulness has been linked to visitor restoration [33].

4.6.The role of positive psychology in tourists' behavioural intentions

Tourists' well-being is significant in tourism marketing as it influences behavioural intentions. Tourism and leisure travel not only increases individual happiness but has also been found to increase tourists' subjective well-being and overall quality of life.

In positive psychology, the outcomes of well-being can be distinguished based on whether they emphasize bottom-up or top-down effects. The bottom-up theory of well-being argues that tourism as a deliberate activity, is an important context for experiencing well-being . A number of tourism studies have demonstrated that tourism experiences can lead to well-being and quality of life. Larsen has argued that a tourist experience is a function of individual psychological processes consisting of three main components: expectations, perceptions and memory. Memories of tourism experiences contribute to an individual's happiness through reminiscent memories. A Memorable Tourism Experience (MTE) has also been claimed to include elements of hedonia and eudaimonia and provide a context for experiencing well-being as it can positively affect life domains such as family and social lives . From this perspective, the MTE context has meaning and can contribute to a well-being outcome [17].

An alternative route to well-being is provided by top-down theory which argues that well-being is affected by a person's internal disposition such as a person's goals in a particular situation. Goals here are considered an internal disposition of a desired end state and can be strongly linked to well-being [16].

The concept of well-being is also significant in tourism marketing as it can influence tourists' choice to visit a particular destination and subsequently, behavioural intentions such as positive word-of-mouth (WOM) and revisit intentions. However, some studies have argued that the relationship between tourism satisfaction and destination loyalty may not necessarily initiate the decision-making process for revisitation [7].

V. CONCLUSIONS

This scientific paper has offered a theoretical reflection on the connections between positive psychology, positive tourism, well-being, and mindfulness towards the development of meaningful tourist experiences [7].

This study underlines the importance of considering both the reflexive and the anticipatory phase of the trip through its focus on the antecedents and outcomes of meaningful tourist experiences to understand what personal, emotional, social, or environmental reasons lead to involvement in a particular experience. So, through the study of antecedents and outcomes of meaningful tourist experiences, it is possible to develop a set of meaningful activities and thus improve stakeholders' well-being and marketing strategies [14].

Despite the different instruments already developed, there is a need to carefully analyse and adapt some of these tools to better understand meaningful tourist experiences. As such, an important theoretical implication consists of improving the already existing instruments that assess the psychological variables under study.[32]

As such, the priority is to introduce a richer perspective on the promotion of these experiences with a holistic lens and to proceed to the development or improvement of new or existing tools to better address them and understand meaningful tourist experiences [15].

This theoretical approach is still at a preliminary stage and must be improved to allow a better tourism management decision, especially during these difficult times when resilience and persistence are being tested. As such, the article offers a theoretical reflection on the connections between the referenced theoretical foundations as proposed in a preliminary diagram illustrating the theoretical links observed; it acts as a first step towards the design of a systematic literature review of the antecedents and outcomes of meaningful tourist experiences. The advantages of this method include the fact that the focus is on the critical subjects in which to invest in future research through demonstrating the important research gaps that will help to better design and justify the research [16].

Studies on tourism and well-being focus mainly on the hedonic perspective. A comprehensive perspective of the meaningful tourist experience from tourism industries requires the consideration of hedonic and eudaemonic well-being. As such, the theoretical investigation and destination managers must explore the eudaemonic perspective and its synergy with positive psychology in the development of positive meaningful tourist experiences, allowing for the emergence of other psychological

components, such as meaning and purpose in life, life satisfaction, accomplishment, mastery, and affiliation [7].

Consequently, managers and tourism industries should invest in the emotional, psychological, and social reactions that contribute to the relational component of the experiences, taking the characteristics of the experiences and also the intrinsic characteristics of stakeholders and their contribution to the development of meaningful tourist experiences into account [16].

Even though the literature argues for the applicability of positive psychology interventions to enhance tourists' well-being, they have not been overly developed. So, the knowledge about the potential of positive psychology for the promotion of well-being can be a powerful tool in the design of travel experiences, which could prove to be another arresting idea for tourism industries: innovate to captivate.

Finally, research stresses the need to improve the participation of other people, which is simultaneously important for the promotion of well-being. This research aims to assure that all stakeholders' needs are considered equally. As such, tourism industries can be responsible for exploring whether the quality of life and satisfaction of the host community is threatened by tourism in order to achieve positive well-being outcomes and help host communities and tourism workers flourish, thus contributing to the optimisation of the experience and the improvement of well-being [7].

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