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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.

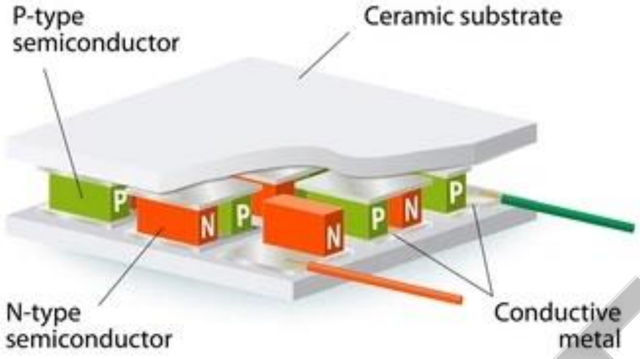

Fig. 1. A thermoelectric module [2]

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]:

$$\eta_{\mathrm{TE}} = \frac{W_{\mathrm{elec}}}{Q_{\mathrm{H}}} = \frac{\Delta T}{T_{\mathrm{h}}} \times \frac{\frac{m}{m+1}}{1 + \frac{(m+1)}{zT_{\mathrm{h}}} - \frac{\Delta T}{2T_{\mathrm{h}} \times (m+1)}} \tag{1}$$

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:

$$\eta_{\mathrm{TE_{max}}} = \frac{W_{\mathrm{elec}}}{Q_{\mathrm{H}}} = \frac{\Delta T}{T_{\mathrm{h}}} \times \frac{\sqrt{1 + zT - 1}}{\sqrt{1 + zT} + \frac{T_c}{T_{\mathrm{h}}}}$$

$$m_{\mathrm{opt}} = \sqrt{1 + zT}\ , \tag{2}$$

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].

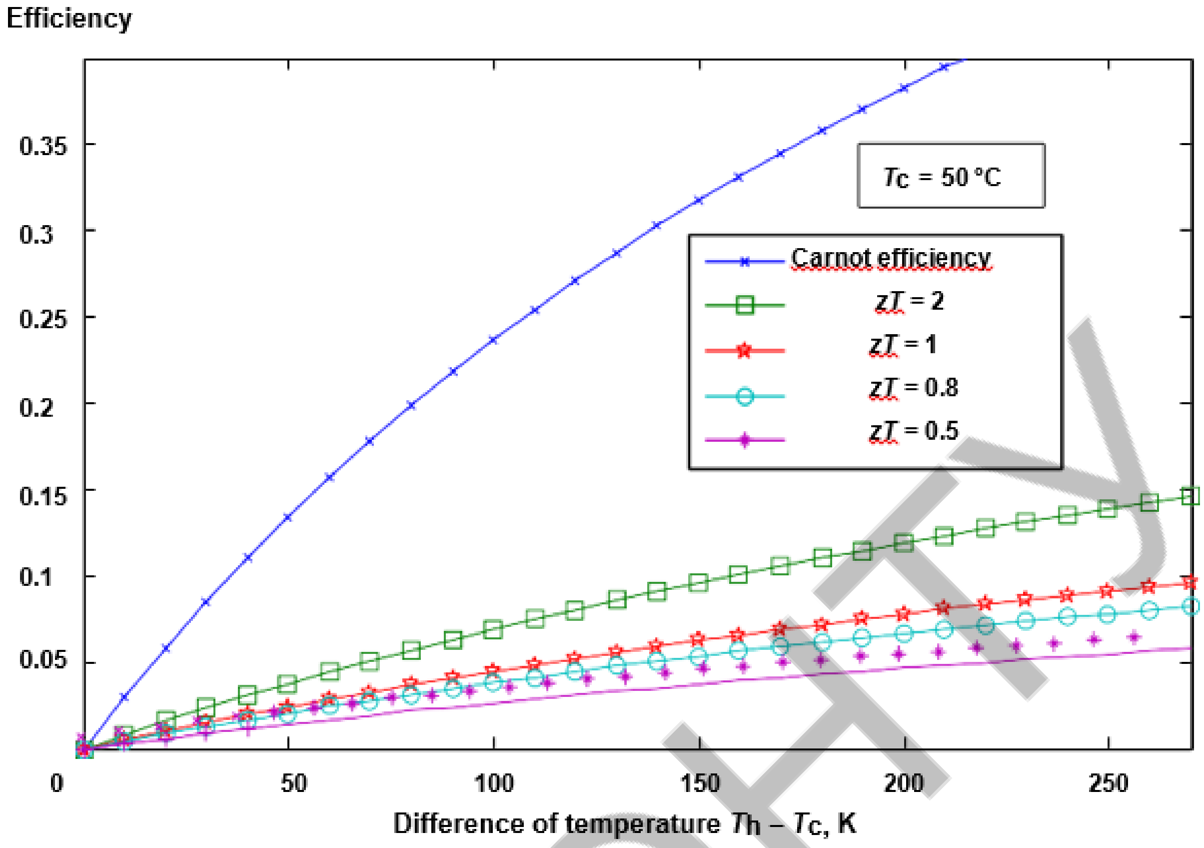

Fig. 2. Dependence of TEM efficiency on the temperature difference between hot and cold surfaces [3]

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.

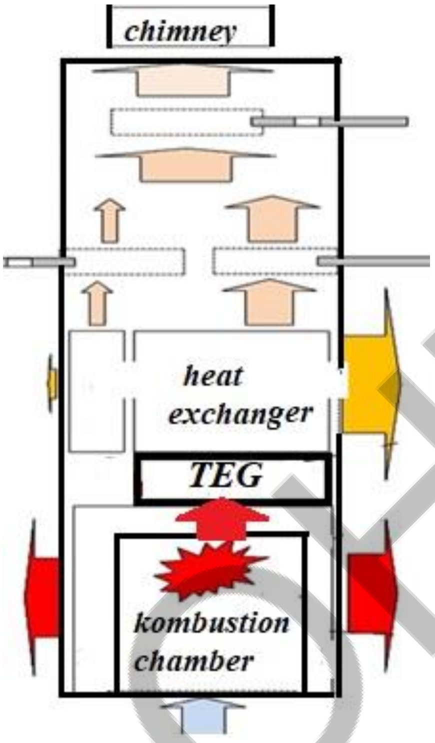

Fig. 3. Location of the thermoelectric generator

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]:

$$W_{\max} = F \times n\left(\frac{\alpha^2}{2\rho}\right)\left(\frac{A}{l}\right)(T_h - T_c) \tag{3}$$

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 $\Delta T = T_1 – T_2$.

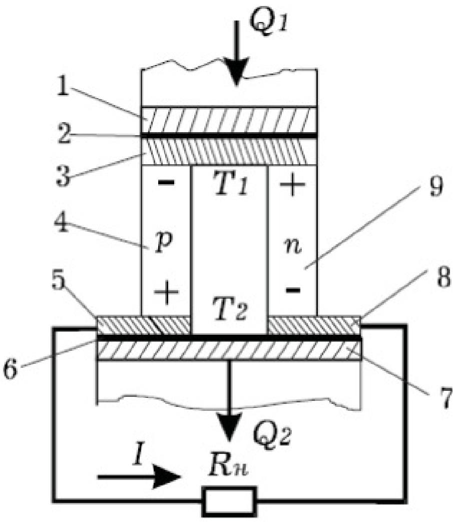

Fig. 4. Thermoelectric generator element

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: $P = Q_1 - Q_2 = I^2 R_H \sim \Delta T^2$.

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).

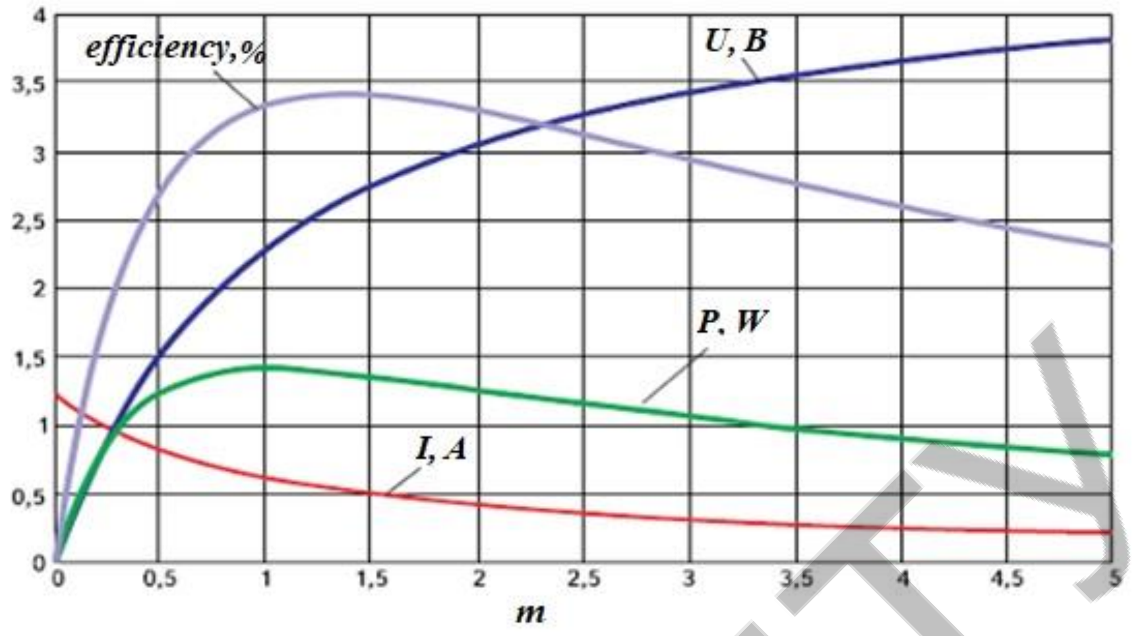

Fig. 5. Dependences of TEM characteristics on the parameter *m* [23]

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 $Bi_2Te_3 – Si\text{-}Ge$ 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.

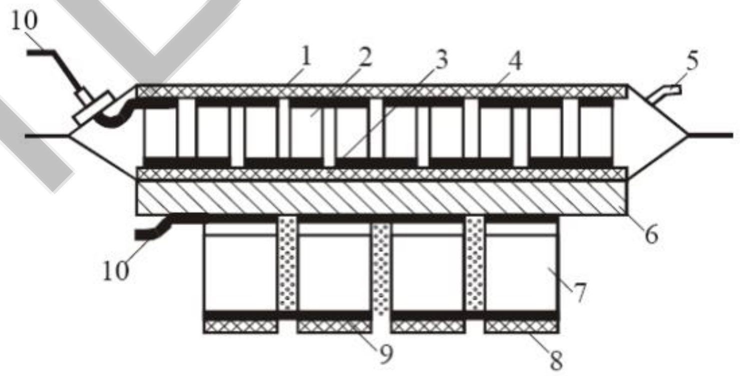

Fig. 6. Scheme of a two-stage thermoelectric module ($Bi_2Te_3 – Si\text{-}Ge$):
1 – sealed housing; 2 – thermoelements of the low-temperature cascade;
3 – electrical insulation; 4, 8 – ceramic plate; 5 – tubulation; 6 – heat transfer;
7 – thermoelements of the high-temperature cascade; 9 – switching 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%.

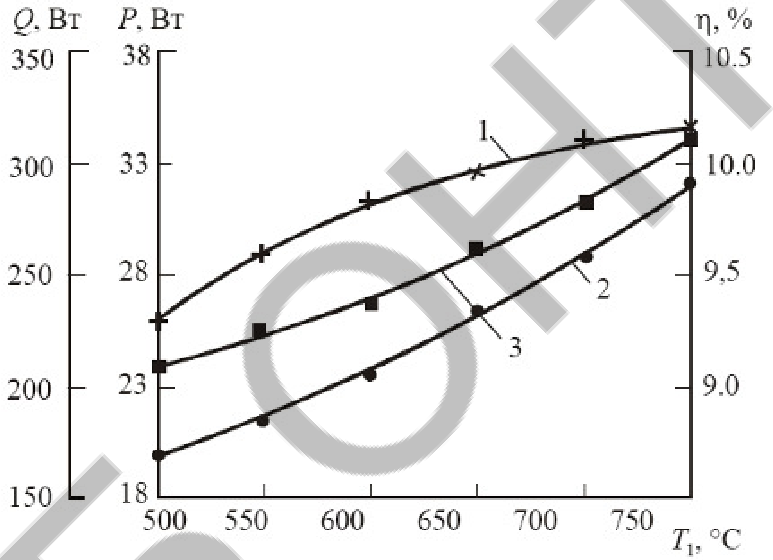

Fig. 7. Dependences of the two-stage module efficiency ($Bi_2Te_3 – Si\text{-}Ge$) η (3), electric power P (1), heat flow Q (2) on the hot side temperature [23]

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:

$$\Phi = W_{max}/\eta = 306{,}9 \approx 300\ W. \qquad (7)$$

Then the maximum thermal resistance is equal to:

$$R_T = \Phi / \Delta T_{\max} = 300 / (750 - 50) = 0.43 \text{ Ohm/K}. \qquad (8)$$

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.

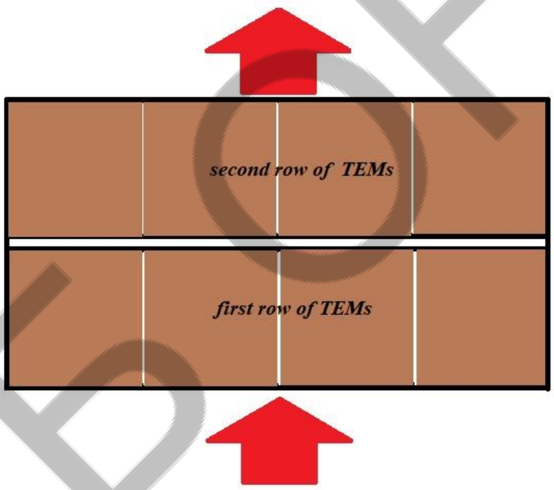

Fig. 8. Location of TEMs in the stove

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.

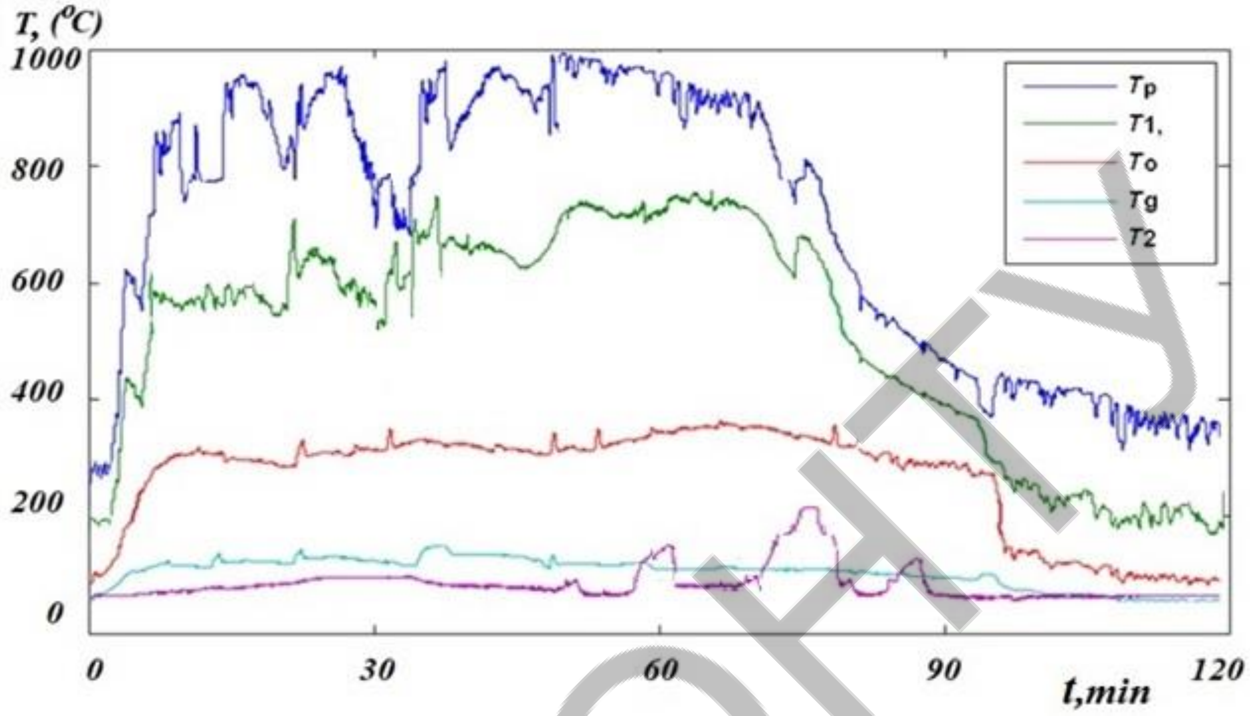

Fig. 9. Simulation of the main temperature parameters inside a household stove T_p – temperature in the upper part of the flame chamber; T_g – flue gas temperature at the stove outlet; T_1 and T_0 – temperature at the inlet and outlet of the heat exchanger; T_2 – cold wall temperature

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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