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В докладах представлены результаты теоретических и экспериментальных исследований ученых и специалистов Казахстана, Германии, России, США, Японии и Украины по направлениям: теплохладоснабжения, кондиционирования и экологии.

Сборник рассчитан на специалистов и ученых, работающих в областях пищевой, химической, нефтеперерабатывающей промышленности, а также гостиничном бизнесе и спортивных комплексах.

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TRIGENERATION AS A METHOD OF HIGH EFFICIENT UTILIZATION OF SECONDARY ENERGY RESOURCES OF THE SHIP POWER PLANT

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For years there has been, and still is, a tendency in the national economy to increase the efficiency of both the marine and inland propulsion systems. New design solutions are searched to increase the efficiency of the propulsion system via using the cogeneration technology to recover the secondary energy resources of ship propulsion.

Cogeneration, also known as combined heat and power (CHP) and total energy, is an efficient, clean and reliable approach to generating power and thermal energy from a single fuel source. Namely, cogeneration uses heat that is otherwise discarded from conventional power generation to produce thermal energy. This energy is

achieve a dramatic improvement in the system's efficiency. In addition, the higher efficiencies of cogeneration reduce air emissions of nitrous oxides, sulfur dioxide, mercury, particulate matter and carbon dioxide, which are the leading greenhouse gases associated with climate change [1].

All these qualities make cogeneration technology very attractive for using in the marine applications. However, such ship recovery system has been recently modified by using the trigeneration technology instead of cogeneration. The advantages of applying trigeneration were evident.

Trigeneration or combined heating, cooling and power (CHCP) production is becoming an increasingly important energy option. Trigeneration can be seen as the simultaneous production of electricity, heat and cooling power from the same source of energy such as natural gas or oil. The literature typically refers to trigeneration as the combination of a traditional combined heat and power (CHP) prime mover such as an engine or a combustion gas turbine, that cogenerates electricity and heat, with an absorption cycle driven by hot water or steam produced by CHP system [2].

CHCP systems incorporate multiple technologies for energy supplying of a single or a campus of buildings, hospitals, medical centers, industrial facilities, etc. These systems provide many benefits such as reduced energy costs, improved power reliability, increased energy efficiency, and improved environmental quality that makes this technology economically attractive.

In trigeneration systems two kinds of ship power plant can be generally used: reciprocating Diesel engines (DEs), and gas turbine plant and each of them can be selected for exactly matching the site conditions [2].

Reciprocating Diesel engines are the most common and most technically mature of all distributed marine technologies. DEs are manufactured in wide range of generating power with up to 7 MW and use commonly available fuels such as diesel fuel.

In addition to DEs, trigeneration systems can utilize gas turbine power plants as prime movers, which are basically produce in the range from 8 MW up to 14 MW of power. Such power plants can use natural gas, propane, diesel fuel and can be divided in two general classes:

- Recuperated power plants, which recover the heat from the exhaust gas to boost the temperature of combustion and increase the efficiency;
- unrecuperated (or simple cycle) power plants, which have lower efficiencies, but also lower capital costs.

In CHCP systems electricity is provided by on-site or near-site power generators. Waste heat from power generation equipment is recovered by operating installations for heating and cooling, which usually are utilizing heat recovery unit with water-LiBr absorption chilling.

Such systems implemented in marine propulsion systems in recent years are based mainly on gas and steam turbines. These systems can reach the efficiency exceeding 60% in inland applications. For example, the marine system of this type was applied by the "Wärtsilä Corp.". However, its main disadvantage is that the system needs a lot of free installation area because of its considerable large size.

As the ship has relatively small holds, the maximal installation area for the recovery unit is strictly limited. Therefore, the requirement for mass and overall dimensions takes the first priority place.

This requirement is primarily concerned with the part of recovery unit, which produces cooling power, i. e. heat driven refrigeration machine (HDRM). Today the most efficient of HDRMs is absorption heat driven machine (coefficient of performance is approximately 0.75), but its size is large and this isn't a good thing in small area conditions. Furthermore, its operational complexity and price are very high.

These problems can be solved in case of using simple and reliable ejector chillers and air conditioners as a heat driven refrigeration machine for different types of ship trigeneration systems (Figure 1). Ejector refrigeration machines (ERMs) are operated with low-boiling point working fluids and powered by heat supplied from ship power systems.

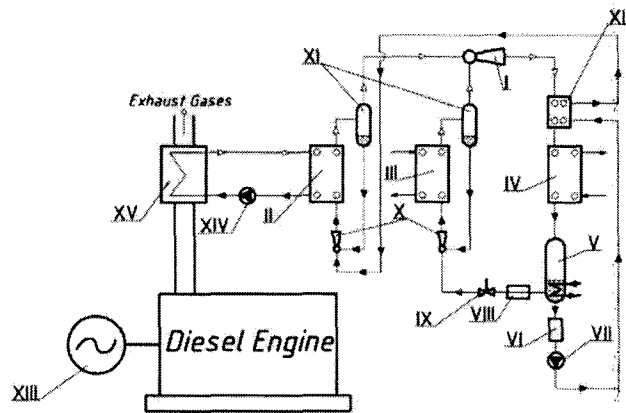


Figure 1 – Diagram of ship trigeneration system incorporated the ERM:
I – Ejector; II – Generator; III – Evaporator; IV – Condenser; V – Receiver-subcooler; VI – Cleaning Filter; VII – Feed Pump; VIII – Drying Filter; IX – TEV; X – Injector; XI – Liquid Separator; XII – Regeneration Heat Exchanger; XIII – Alternator; XIV – Water Pump; XV – Recovery Boiler

Such waste heat recovery would ultimately reduce overall fuel consumption and carbon dioxide production and thus help to alleviate global climatic change brought about by the greenhouse effect.

ERMs have such advantages over other heat powered refrigeration cycles as simplicity in design, high reliability and durability, low installation cost, small maintenance and repair expenses.

The basic components of the ejector chiller include an ejector, a generator, an evaporator, a condenser, an expansion valve and a feed pump. The thermal energy of the exhaust gases is transferred through a heat recovery unit to a water circuit serving the generator of the chiller. Low boiling refrigerant is heated by the low grade heat energy Q_g rejected from the heat recovery unit into the generator, where liquid refrigerant is vaporized at relatively high pressure P_g and temperature T_g . This primary vapor with a mass flow rate of \dot{m}_p flows through the primary convergent-divergent nozzle of the ejector and expands at the exit of the nozzle. The relatively low-pressure produced by this expansion causes a suctioning effect of secondary flow with a mass flow rate of \dot{m}_e from the evaporator at low pressure P_e . The primary and secondary fluids are mixed in the mixing section of the ejector and undergo a pressure recovery process in the diffuser section. The combined stream flows to the condenser where it is condensed to liquid at intermediate pressure P_{cand} and temperature T_c . The heat of condensation Q_c is rejected to the environment. From the condenser, a portion of the liquid refrigerant is pumped back to the generator, while the remainder is expanded through an expansion valve and enters the evaporator, where it is evaporated at temperature T_e thus completing the cycle. The resulting cooling effect Q_e can be used to provide air conditioning and space cooling to the local community or to improve the thermal efficiency of the engine cycle by cooling the charge air prior to ingestion to the engine cylinders. Thus, the main part of the exhaust heat can be recovered.

The only drawback of the ERMs was their relatively low COPs, usually not higher than 0.3.

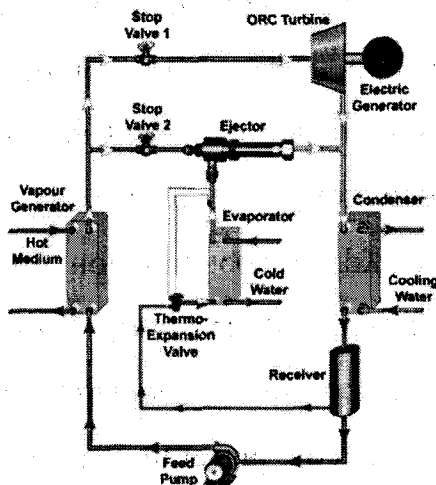


Figure 2 – Diagram of hybrid ORC-ERM

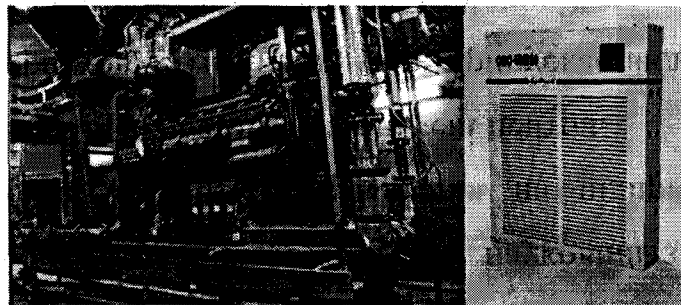


Figure 3 – The overall dimensions comparison of the standard

Recently several high efficiency ERMs, operating with refrigerants R141b and R245fa, were developed and coefficients of performance (COPs) in the range of 0.5 – 0.7 were obtained at practical operating conditions. These results are very encouraging for air-conditioning and cooling applications because these COPs are similar to those for absorption cycle machines [3,4,5].

Thus, the trigeneration systems with ERMs could be suitable alternative to that with water-LiBr absorption systems [5].

In ONAFT the new way to further reduction of the trigeneration system's overall dimensions is researched. It represents a system operated by the combined ejector cycle and organic Rankine cycle. The new recovery unit is called Hybrid ORC-ERM machine. As both the steam power plant and the ERM have the same apparatuses (generator, condenser and pump), a hybrid trigeneration machine can be designed. The diagram of hybrid ORC-ERM machine is shown on Figure 2. On Figure 3 the classic trigeneration system and the hybrid ORC-ERM machine are shown for a comparative analysis. The big difference between overall dimensions of these recovery plants is visible. Finally, there are the simplest and cheapest continuously working trigeneration systems among other hybrid cycles.

CHCP systems, when designed to operate independently from the grid, can provide critical power reliability for a variety of ships while providing electric, thermal and refrigeration energy to the sites on a continuous basis, resulting in daily operating cost savings. CHCP systems can be configured in a number of ways to meet the specific reliability and risk profiles of various customer needs, and to offset the capital cost investment for traditional backup power measures. Replacing the large and expensive Li-Br absorption chillers with the ERMs allows to obtain the compact and cheap trigeneration units which are ready to be installed in different vessels and ensure the efficient and reliable operation in any operational condition.

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