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NOVEL THERMOCHEMICAL SYSTEM FOR MARINE POWER PLANT

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Abstract. The work is devoted to the study of the possibilities of using a thermochemical system for recuperating the heat of waste gases to improve the efficiency of marine power plants. The analysis carried out allows us to state that the thermochemical treatment of a number of hydrocarbon fuels is promising and that the energy and environmental performance of modern heat engines and installations can be improved.
Keywords: thermochemical system; heat engine; marine power plant; environmental indicators.

Introduction. The need to comply with the requirements of the International Maritime Organization (IMO) legislation to reduce the environmental impact of marine energetics determines the demand for practice aimed at developing and adopting energy-efficient technologies [1]. This scientific and practical problem could be solved by comprehensive implementation of innovative power plants, defining the ranges of their achievable parameters, as well as the development of scientifically sound promising scheme solutions that improve fuel efficiency in Ukraine and China, minimize CO2 emissions and other harmful substances.

To increase the efficiency of fuel energy consumption in marine power plants and reduce emissions, it is proposed to use the idea of thermochemical treatment of hydrocarbon and methanol fuels by steam conversion at parameters that are consistent with the parameters of operating processes of power plants and waste energy products, as well as subsequent low-emission combustion of thermochemical transformation products in combustion chambers with preliminary partial mixing of fuel and oxidant.

Due to the specific characteristics of every transformational technology, some of them will only apply to one specific sector (commercial shipping, naval, ocean space), whereas others will apply to two of them, or to all of them. The geography of world trade increases the impact of the transport system and its main component - the transportation of goods by the sea on the state of the world economy. According to a report by the United Nations Conference on Trade and Development (UNCTAD), more than 70% of the value of world trade is carried onboard ships [2].

One of the promising areas for improving the efficiency and environmental friendliness of marine power plants is the utilization of secondary energy resources of heat engines [3, 4]. Thermochemical technologies, which are technologies for the utilization of secondary energy resources, allow to expand the scope of alternative fuels and provide the possibility of efficient energy use of different heat engines in ship power complexes, primarily in joint units with electric propulsion.

Main part. Thermochemical treatment of hydrocarbon and methanol fuels is a set of processes as a result of which the enthalpy of regenerating energy carrier (a mixture of hydrocarbon fuel and oxidant) increase. Thermochemical transformation proceeds with a change in its chemical composition due to the endothermic process of conversion of base (source) fuels.

Fig. 1 and 2 show diagrams of thermochemical treatment of hydrocarbon base fuel by steam conversion due to regeneration / utilization of heat of exhaust gases of a heat engine.

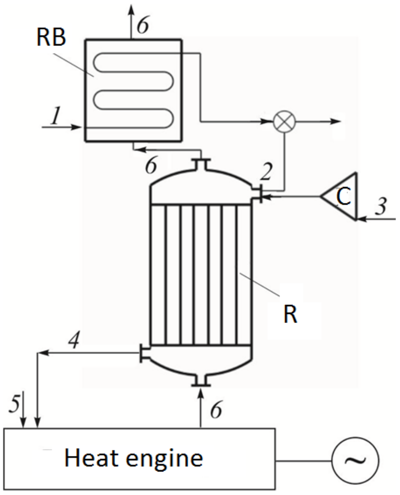

Fig. 1 – Schematic diagram of thermochemical treatment of base fuel:
RB - recycling boiler; C - compressor; R - thermochemical reactor; 1 - water; 2 - steam; 3 - hydrocarbon fuel; 4 - synthesis gas; 5 - air; 6 - engine exhaust

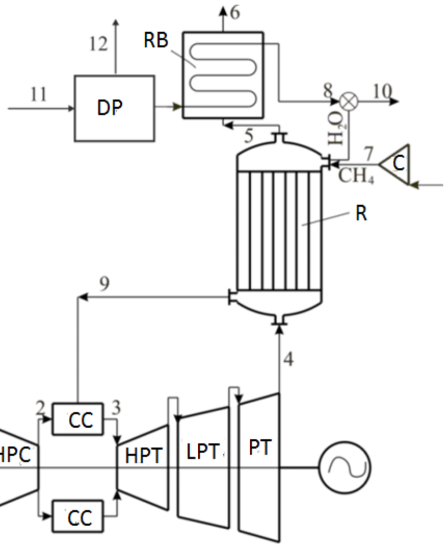

Fig. 2 – Diagram of the power module with thermochemical processing of fuel:
LPC - low pressure compressor; HPC - high pressure compressor; CC - combustion chamber; HPT - high pressure turbine; LPT - low pressure turbine; PT - power turbine; R - reactor; RB - recycling boiler; C - base fuel compressor; DP - desalination plant

The concept of thermochemical utilization of secondary energy resources of marine heat engines corresponds to the main trends in the development of marine power plants, given in the analytical review of Global Marine Technology Trends 2030, prepared by the Lloyd's Register. According to this forecast, the promising areas for the next 15 years will be:

1) use of alternative fuels;

2) the use of diesel-electric, combined, and hybrid power plants;

3) improvement of technologies for utilization of secondary energy resources.

Being technologies of utilization of secondary energy resources, thermochemical technologies will allow to expand the scope of application of alternative fuels and will provide an opportunity to use different types of heat engines as a part of uniform electric generating power plants.

Thermochemical technologies involve the conversion of base fuel using the thermal energy of exhaust gases. Alternative fuels such as ethanol / bioethanol, methanol, natural gas, petroleum associated gas of various compositions, gaseous fuel based on heavy hydrocarbons (ethane, propane, butane, and others) can be used as the base energy source.

Investigations of thermochemical technologies of fuel treatment have been carried out in the world for a number of recent years, but comprehensive studies of the efficiency of marine power plants based on utilization thermochemical technologies are virtually absent.

Despite the results achieved in the field of thermochemical utilization, methodological and technical aspects of solving the problem of creating technologies for thermochemical utilization of secondary energy resources of marine power plants have not yet been fully developed. Comprehensive research in this direction is practically absent in Ukraine.

Note that to obtain an increased amount of molecular hydrogen in the synthesis gas as a reactor for the thermochemical treatment of liquid fuel a plasma-chemical generator of hydrogen-containing gas (Fig. 3) was previously developed in the Admiral Makarov National University of Shipbuilding

(NUS) [4, 5]. The principle of its operation is based on the plasma conversion of the base fuel in the presence of insufficient amount of oxidant for combustion: air or steam.

For experimental researches of processes of thermochemical transformations, it is planned to use the experimental equipment of the Center of perspective energy technologies of research institute "Energy and mechanical engineering" of NUS. The experimental setup consists of a subsystem of preparation and supply of basic water-ethanol mixture, a subsystem of thermochemical treatment of the mixture, a subsystem of synthesis gas processing, which includes cooling and condensation units of conversion products, condensate removal, compression, and injection of synthesis gas into engine cylinders. The general view of the setup is presented in Fig. 4.

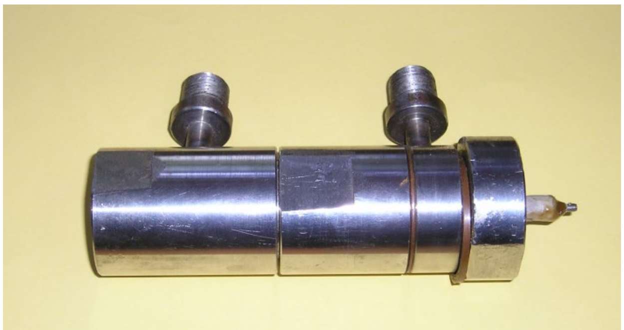

Fig. 3 – Plasma-chemical generator of hydrogen-containing gas

Fig. 4 – General view of the experimental setup for thermochemical process investigation

At Jiangsu University of Science and Technology, China, there is a research team deals with the design, optimization, and experimental proof of thermochemical fuel cells for marine use (Fig. 5, 6). One of the most pressing issues in the implementation of promising energy modules is the possibility of fuel cells running on various hydrocarbon and methanol fuels, which requires the development of external thermochemical systems to produce synthesis gas with high hydrogen content.

Fig. 5 – Power system with 4 kW fuel cells to study the possibilities of use on ship

Fig. 6 – 3 kW Solid Oxide Fuel Cell stack testing system

Preliminary investigations of thermochemical transformation processes have proved the prospects for the use of such systems in marine energetics.

Conclusions. 1. For the first time, new patterns have been obtained, which take into consideration the complex effect of temperature, pressure, and the ratio of water vapor / base fuel on the coefficient of increase of the calorific value of the base fuel.

2. Indicators of efficiency of thermochemical treatment of hydrocarbon and methanol fuels for ranges of temperatures and pressures which correspond to parameters of working processes of thermal engines of marine power plants have been determined.

3. The obtained results will significantly expand the understanding of the physics-chemical mechanisms of environmentally friendly burning in combustion chambers operating on the thermochemical products.

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АНАЛІЗ МОЖЛИВОСТЕЙ СТВОРЕННЯ ЦИФРОВОГО ДВІЙНИКА ПРОТОТИПУ ТЕРМОСИФОННОГО ТЕПЛООБМІННОГО АПАРАТУ

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Анотація: Проаналізовано можливість використання технології цифрового двійника для створення прототипу теплообмінника на двофазних термосифонах. Сформовано задачі декомпозиції математичної моделі теплообмінника та визначено основні критерії та інженерні/цифрові інструменти для визначення характеристик і коефіцієнтів, що описують роботу термосифона.

Ключові слова: цифровий двійник, термосифон, теплообмінник.

Вступна частина. Цифровий двійник – це цифрова (віртуальна) модель будь-яких об'єктів, систем, чи процесів. Вона точно відтворює форму та дії оригіналу та синхронізована з ним. Технологія цифрових двійників дозволяє створювати окремі деталі та відтворювати цілі виробничі ланцюжки, проводячи віртуальні випробування та запобігаючи збоям у роботі обладнання [1, с. 3].

Мета роботи. При розробці нового енергетичного обладнання використання технології цифрового двійника дозволить суттєво знизити витрати часу і фінансів, оскільки ще на етапі