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ANALYTICAL REVIEW OF THE PROBLEMS OF IMPROVING THE ENERGY EFFICIENCY OF DIESEL ENGINES AND REDUCING ATMOSPHERIC AIR POLLUTION

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ABSTRACT

The paper analyzes the main directions for improving the energy efficiency of marine diesel power plants and reducing atmospheric air pollution from exhaust gases. Numerical study of fuel spraying characteristics by diesel injectors at injection pressures in the range from 50 to 300 MPa has been conducted.
Based on the analysis of the known designs of thermally insulated combustion chambers, the technology of manufacturing a pilot piston is proposed, which is based on the application of a ceramic coating using zirconium dioxide powder on the walls of the combustion chamber of the mass-production piston.

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Introduction.

A significant proportion of global energy generation (more than 30%) is consumed in transportation. Of this, the most part (almost 95%) refers to energy generated through the burning of petroleum fuels.

Water transport is among the main consumers of liquid hydrocarbon fuel, where diesel engines are the main energy source. Currently and in the near future, diesel engines are the main energy source on ships of the sea and river fleet.

The running diesel engine is an intensive source of noise, thermal, and chemical pollution in the environment.

The problem of reducing pollutant emissions from diesel engines is among the most important tasks of the diesel engine industry, on the solution of which the state of human health and the preservation of the gene pool depend.

The first international standards limiting emissions of harmful substances (pollutants) with exhaust gases from marine diesel engines were adopted on September 26, 1997 by the International Maritime Organization (IMO) in the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78). This policy document came into force on January 1, 2000 [1].

An integral part of Annex VI of the MARPOL 73/78 convention is the "Technical Code on Emissions of Nitrogen Oxides from Marine Engines". This document regulates the specific weighted emissions of pollutants contained in the exhaust gases of diesel engines.

In the United States, control powers in the field of atmospheric air protection are exercised by the "Environmental Protection Agency" (USEPA) [2].

In EU countries, for marine diesel engines in the river fleet, control over the emissions of harmful substances into the atmospheric air is exercised by the Rhine Commission (RCINC). This Commission, in turn, is subordinated to the European Environment Agency (EEA) [3].

Since 2009, the European standard "Emission Limits for European Waterways" (Stage III A) has come into force.

In 2016, the MARPOL 73/78 regulations in the Controlled Emission Zones, which include the North American coast of Canada, the USA, the Baltic Sea, the North Sea, and some areas of the Chinese coast, introduced Tier 3 standards, providing for a reduction of nitrogen oxide emissions by 80%.

Figure 1 illustrates the dynamics of tightening harmful emission standards from marine diesel engines in the revised MARPOL 73/78Annex VI regulations.

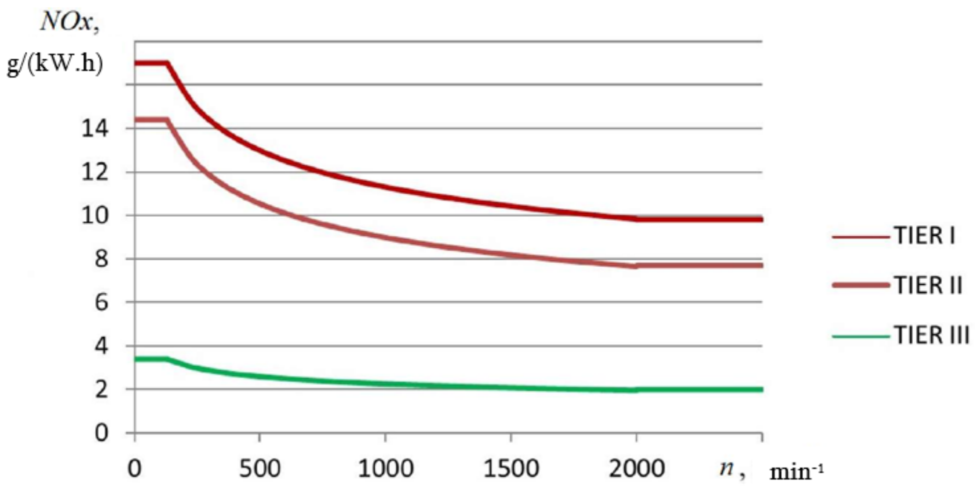

Figure 1. Dependence of specific values of specific weighted emissions of nitrogen oxides on frequency of rotation of a cranked shaft.

Research findings.

Specific effective fuel consumption (g/kWh) is considered to be an indicator of energy efficiency for a marine diesel unit.

Specific indicator fuel consumption depends only on the quality of implementation of the working process and the amount of heat losses.

In the general case, the working process in a diesel engine can be represented in the form of separate components that are inseparable, interrelated, and have a significant effect on each other. These include the processes of fuel supply, mixture formation, and combustion.

The mixture formation process can be improved by the following methods:

a) Increasing fuel injection pressure.

b) Application of gas additives to fuel.

c) Charge-air swirling.

d) Application of magnetic and electric fields.

The combustion process is the basis of the working process and has a major impact on the energy and environmental performance of marine diesel engines. Combustion is a process of rapid chemical reactions in a substance that in the initial state is inert. The main physical phenomenon accompanying the combustion process, which is of the greatest interest to us and will be the subject of research, is the process of heat release [4].

The main criteria for the quality of the combustion process in a diesel engine are the rate and completeness of fuel combustion, as well as the timeliness of heat supply to the working body.

The combustion process is conventionally represented by four components:

- ignition delay period;
- period of kinetic combustion;
- period of diffusion combustion;
- after-burning period.

The main period, which has a determining influence on the heat release process, is the third period – the period of diffusion combustion.

In this period, the combustion rate of sprayed fuel droplets is limited by the rate of their evaporation and the rate of diffusion of fuel vapor and air.

To improve the energy performance of the diesel engine, it is desirable to reduce the duration of the third period and eliminate completely the fourth period.

It is possible to improve the efficient use of heat and indicator efficiency by reducing heat losses in the cooling medium.

The following means are known to reduce heat loss:

- High-temperature cooling systems.
- Heat-insulating coatings on the surface of cylinder liners.
- Thermal insulation of combustion chambers using composite pistons, special liner overlays on the piston head, and coating of the piston bottom with materials having low thermal conductivity [5, 6].

The research results in this area are mixed and inconsistent.

The exhaust gases of piston engines contain more than 1200 different chemical compounds. The known ways to reduce emissions of harmful (polluting) substances in marine diesel engines can be conditionally divided into 3 main directions:

1) External - realized outside the cylinder.

2) Internal - realized inside the cylinder.

3) Use of alternative, environmentally friendly fuels.

External methods of reducing pollutant emissions include cleaning, afterburning, and reduction. Cleaning and after-burning reduce the concentration of particulate matter, carbon monoxide, and hydrocarbons. The reduction of nitrogen oxides in exhaust gases is carried out through selective catalytic reduction to molecular nitrogen.

Internal methods of reducing pollutant emissions include improving the processes of fuel supply, mixture formation, and combustion, as well as through the use of various additives to fuel and air.

The essence of internal methods is to increase the completeness and timeliness of the implementation of the combustion process. The advantage of these methods is the potential possibility to increase the indicator efficiency of diesel engines while reducing harmful emissions [8 – 11].

At present, the main direction of complex improvement of economic and environmental performance abroad is the increase of fuel injection pressure with the use of electronic microprocessor control of fuel supply and gas exchange.

The use of alternative, environmentally friendly fuels to reduce pollutant emissions is considered very promising, despite the higher cost of such fuels [7, 12].

Alternative fuels include compressed and liquefied natural gas, gas condensate, various vegetable oils, alcohols, dimethyl ether, biogas, and hydrogen [12]. The most promising of the listed fuels at present are compressed and liquefied gases.

According to the method developed by Professor S.A. Kalashnikov, based on dependences obtained by Rozin and Rammler, a numerical study of fuel spraying characteristics by diesel injectors at injection pressures in the range from 50 to 300 MPa has been conducted. Figure 2 illustrates diesel fuel's total and differential spraying characteristics by multi-hole injectors at different injection pressures [13].

Figure 2 shows that with increasing injection pressure, the droplet size decreases, and spraying becomes finer and more homogeneous, which provides better micro-mixing and combustion.

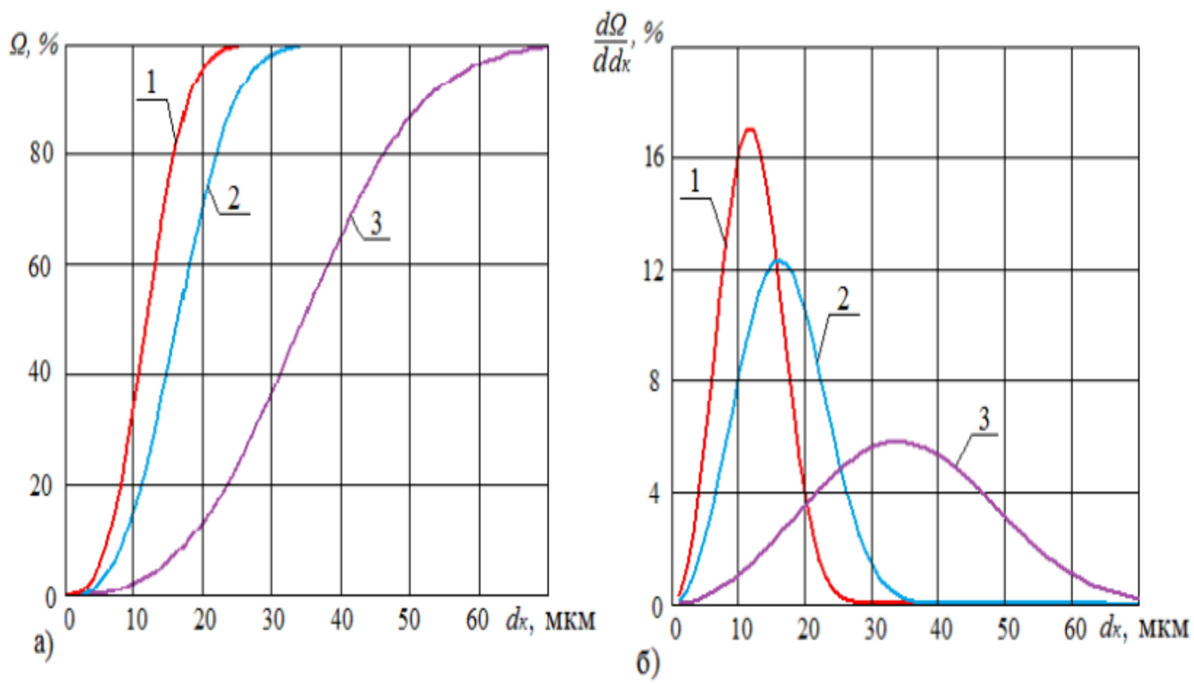

Fig. 2. Diesel fuel spraying characteristics:
a) Combined characteristic, b) Differential characteristic:
1 – Spraying pressure - 300 MPa, 2 – 150 MPa, 3 – 50 MPa.
Ω – the ratio of the volume of droplets with diameters from the minimum to the given one, to the total volume of all droplets; dΩ/ddк – probability density function of droplets of given diameter; dk – droplet diameter.

The research was carried out in the research laboratory of the Faculty of Engineering of the Batumi State Maritime Academy. In Fig. 3 shows a photograph of the research object, and Fig. 4 – photograph of a research piston.

Fig. 3. Research object.

Fig. 4. Piston construction.

Based on the analysis of known designs of thermally insulated combustion chambers, a technology for manufacturing a prototype piston has been proposed that is based on applying a ceramic coating using zirconium dioxide powder to the walls of the combustion chamber of the mass-production piston.

To that end, the technology of applying thermal insulating coating was developed, and models of experimental pistons with a thermally insulated combustion chamber were manufactured, with a flat and profiled upper surface, which was intended to excite gas dynamic vibrations in the form of a radial standing wave.

Conclusion.

The analysis of the published papers showed that, despite a significant amount of theoretical and experimental research, the obtained results are ambiguous and sometimes even contradictory. Therefore, it is necessary to conduct comparative experimental research on water-free diesel fuel, water-fuel emulsion, and vegetable oil when working on standard and experimental heat-insulated pistons.

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