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ASSESSMENT OF THE EFFICIENCY OF BIOFUEL USE IN THE OPERATION OF MARINE DIESEL ENGINES

The object of research is the process of operation of marine diesel engines using biodiesel fuel. The subject of research is the process of experimental determination of the optimal concentration of biodiesel fuel in a mixture with fuel of petroleum origin. At the same time, a simultaneous maximum increase in environmental and minimum decrease in the economic parameters of the operation of a marine diesel engine should be ensured.

The studies were carried out on Hyundai Heavy Industries 5H17/28 marine diesel engines. Three such diesel engines were part of the power plant of a specialized marine ship with deadweight of 9600 tons. The study was aimed at determining the concentration of biofuel in a mixture with diesel fuel, which provides the best environmental performance of a diesel engine. The fuel supply circuit to the first diesel did not change and the diesel was operated on RMB30 fuel. Two other diesel engines were operated on a fuel mixture – RMB30 fuel and B99.9 FAME biofuel. The content of biofuel in the mixture varied in the range of 5–20 %. The main quantities measured during the experiment were the concentration of nitrogen oxides and the volumetric content of carbon monoxide in the exhaust gases, as well as the specific effective fuel consumption. By switching groups of consumers, the operation of diesel engines was carried out at the same load, the support of which was required during the experiment. The load on diesel engines during the experiments varied in the range of 55–85 % of the nominal value. The operation of diesel engines in each of the studied modes was carried out for at least 1.5–2 hours, during which the main parameters were measured and the obtained values were averaged.

It has been established that the use of biofuel increases the environmental friendliness of the marine diesel engine:

– by 7.6–26.61 % (depending on the diesel loading and the content of biofuel in the fuel mixture), the emission of nitrogen oxides with exhaust gases is reduced;

– by 3.8–23.6 % (depending on diesel loading and biofuel content in the fuel mixture) reduces the emission of carbon oxides with exhaust gases.

It has been also determined that when using biofuel, there is an increase in the specific effective fuel consumption by 0.5–8.65 %, which reduces the efficiency of a diesel engine.

The optimal composition of the fuel mixture containing biofuel is proposed to be determined experimentally for each diesel load, taking into account its environmental and economic indicators.

Keywords: *marine diesel, fuel of biological origin, fuel mixture, emission of nitrogen oxides, emission of carbon oxides.*

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1. Introduction

Sea and inland water transport, providing transportation of goods and passengers, consumes a large amount of fuel. On sea and river ships, steam turbine, gas turbine and diesel plants are used as heat engines. At the same time, diesel engines are installed on all ships without exception, regardless of their type, class and deadweight [1, 2]. The effective power of diesel engines is used to propel the ship or provide electrical energy to ship equipment, mechanisms and systems. It is impossible to obtain it without fuel combustion in the cylinder [3]. Modern scientific projects aimed at the use of solar energy and wind energy can only be partially applied in maritime transport. The installation of solar panels on open decks requires their constant dismantling before and after cargo operations. The use of wind generators and rigid sails increases the aerodynamic drag when hydrometeorological conditions deteriorate [4, 5]. The use of rechargeable batteries on transport ships requires constant restoration of their capacity, which is impossible in sea crossings [6]. Thus, liquid fuel will remain the main source of energy for ship power plants for the foreseeable future. At the same time, the world's demand for fuel is constantly increasing, its natural reserves are declining every year, and production volumes are regulated by producing countries. At the same time, the requirements that apply to the environmental performance of the power plants of ships of sea and inland water transport are being tightened:

– expanding special zones for controlling emissions of sulfur oxides with exhaust gases – Sulfur Emission Control Areas [7];
– concentration of nitrogen oxides in exhaust gases is regulated [8];
– emissions of carbon oxides are limited [9].

All this is one of the reasons for the use of alternative fuels, non-petroleum origin, in ship power engineering. Intensive studies of the possibility of its application are currently being carried out in various countries. The main types of alternative fuels are:

– liquefied combustible gases;
– hydrogen;
– alcohols and their mixtures with petroleum fuels;
– vegetable oils;
– artificial liquid and gas fuel (biofuel and biogas) [10, 11].

The study of alternative types of marine fuels (including fuels of biological origin) and the study of their impact on the economic and environmental performance of marine diesel engines is an urgent task. Its solution will help improve the operational parameters of marine diesel engines and reduce their negative impact on the environment.

2. The object of research and its technological audit

The object of research is the process of operation of marine diesel engines using biodiesel fuel.

The subject of research is the process of experimental determination of the optimal concentration of biodiesel fuel in a mixture with fuel of petroleum origin. At the same time, a simultaneous maximum increase in environmental and minimum decrease in the economic parameters of the operation of a marine diesel engine should be ensured.

Fuels for marine diesel engines are traditionally divided into heavy and light. This gradation is related to their specific gravity/density. The density of heavy grades of fuel is 950–980 kg/m^3 (in this case, cases of using fuel with a density of more than 1000 kg/m^3 are possible). The lung density is 850–900 kg/m^3. It is impossible to provide high-quality fuel injection with a similar density through the spray nozzles of marine diesel engines. Therefore, the fuel is subjected to heating, during which not only the density, but also the viscosity of the fuel changes. Heavy fuels include fuels whose viscosity at 50 °C exceeds 50 sSt (modern diesel engines use fuels with a viscosity of up to 500–700 sSt). Light fuels are characterized by a viscosity of 2–40 sSt. The operation of marine diesel engines in steady-state conditions (at a load of 25–110 %) occurs on heavy fuel. In this range of operation, the thermal state of the diesel cylinder group ensures the concentration of energy from air compression in the upper part of the cylinder, which ensures reliable self-ignition of the fuel. The auto-ignition temperature of light fuels is lower than that of heavy fuels. Therefore, light grades are used when starting and reversing a diesel engine. In these modes (due to the low frequency of rotation of the diesel shaft), the thermal energy of compressed air is dispersed throughout the cylinder. This reduces the air temperature at the moment of fuel injection and may be the reason for the absence of self-ignition of the fuel [12, 13].

The composition of heavy fuel (compared to light fuel) includes an increased content of sulfur (up to 0.5 %) and nitrogen (up to 1.0 %). When they are burned, toxic components are formed – oxides of sulfur SO_X, carbon CO and nitrogen NO_X, which adversely affect the environment and humans. In this regard, much attention has recently been paid to the reduction of harmful substances in combustion products, especially nitrogen oxides NO_X [14, 15].

Increased attention to the possibility of using alternative fuel in ship power plants is due to the following reasons:

– combustion of alternative fuels produces less harmful emissions;
– production of alternative fuels is possible from inexhaustible sources;
– use of alternative fuels reduces the state's own energy dependence on external countries and manufacturers.

Fuels of biological origin (vegetable oils, vegetable oil esters, as well as their mixtures) have been considered in recent years as a real alternative to petroleum fuels.

The use of biodiesel fuel in maritime and inland waterway ships is limited by the following reasons:

– autonomy of navigation and the impossibility of unhindered restoration of fuel supplies (including alternative) [16];
– high power of the ship power plant and, accordingly, high fuel consumption [17];
– the need to coordinate all work to improve the fuel system with qualification societies that carry out technical control over the ship and power plant [18].

It should also be noted that the use of only biodiesel fuel to ensure the operating cycle of a marine diesel engine is impossible due to its low calorific value. At the same time, fuel mixtures consisting of diesel fuel (as the main component) and biofuel with a concentration of up to 20–25 % (as an impurity) are being introduced in ship power engineering. Similar performance characteristics of biofuels and diesel fuels (density, viscosity, flash point) allow creating their mixtures directly on the ship without the use of special high-tech equipment.

3. The aim and objectives of research

The aim of research is to determine the concentration of biofuel in its mixture with diesel fuel, which provides the best environmental performance of a diesel engine.

This aim can be achieved by solving the following objectives:

1. Find a section of the forensic fuel system where it is advisable to mix biofuel and diesel fuel.
2. Create criteria by which it is necessary to evaluate the efficiency of biofuel use.
3. Determine the optimal composition of the fuel mixture containing biofuel.

4. Research of existing solutions to the problem

Ensuring the environmental friendliness of the operation of ships of sea and river transport is mainly associated with maintaining the environmental parameters of the operation of ship internal combustion engines. The problem of reducing the concentration of sulfur oxides in the exhaust gases is solved by using fuel with a content of up to 0.5 % in the heat engines of sea and river ships [19].

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Reducing the emission of nitrogen oxides is possible through primary and secondary methods. Primary ones provide a reduction in the NO_X formation during the combustion of fuel in a diesel cylinder. Secondary – reduce the content of nitrogen oxides in exhaust gases.

The most widely used primary methods for reducing NO_X emissions are as follows:

1) boost air humidification;
2) use of water-fuel emulsions;
3) use of direct water injection into the diesel cylinder;
4) modernization of the design of fuel equipment;
5) use of the exhaust gas recirculation system [20, 21].

The first option provides for an additional injection of fresh water into the volume of air entering the diesel cylinder. Injection is carried out by a special nozzle installed either after the charge air cooler or directly in the scavenge air receiver. Entry of moistened air into the cylinder requires additional expenditure of thermal energy for its evaporation, which helps to reduce the temperature in the diesel cylinder during fuel combustion. The disadvantage of this method is the need to control the quality of fresh water supplied to the air receiver [22, 23].

The second option is provided by creating a highly homogeneous mixture of water and fuel and feeding the resulting emulsion into the diesel cylinder. In this case, the temperature also decreases in the process of fuel combustion, and the central part of the fuel flame is additionally enriched with oxygen, which is formed during the evaporation of water. However, given that the amount of fuel supplied to the cylinder must remain constant, additional water supply (the optimal amount of which is in the range of 15–20 %) leads to an increase in the duration of injection of a portion of the emulsion, compared with the injection of «clean» fuel. This makes it necessary to increase the advance angle of the fuel supply, which can lead to the injection of the emulsion into the air, the temperature of which does not yet ensure reliable self-ignition [16, 24].

The third option provides for direct injection of water into the diesel cylinder and is carried out either by common (when fuel and water are supplied through a common nozzle) or by separate injection (when water and fuel are injected into the cylinder through individual nozzles). However, this option also contributes to unstable fuel combustion [25, 26].

The fourth option for ensuring the required level of NO_X emission by primary methods is associated with improving the design of the fuel equipment (changing the shape of the injector nozzle, increasing the fuel injection pressure, etc.) and is associated with the modernization of the entire high-pressure fuel system [19, 27].

The fifth option, the use of an exhaust gas recirculation system, is being actively developed at the present time and has a positive experience of application on marine ships, but requires significant financial investments [28, 29].

Among the secondary methods for reducing NO_X emissions, the Selective catalytic reduction systems, in which exhaust gases are purified in special reactors, are most widely used [30, 31].

The use of alternative fuels is one of the primary methods for reducing NO_X emissions. However, despite the use of various types of alternative fuels, there are no general recommendations for determining its optimal concentration in diesel fuel. Also, there are no recommendations on the economic and environmental efficiency of its use in various diesel operating modes.

5. Methods of research

It is most expedient to use alternative fuels in marine medium-speed diesel engines with a capacity of 500–1000 kW, which are used as auxiliary engines. In this case, with a total average load on the ship power plant of 350–750 kW, the daily fuel consumption is 1680–3600 kg/day. With a biofuel concentration in the fuel mixture of up to 20 %, its daily consumption will be 350–700 kg/day. With navigation autonomy of up to 30 days, such volumes can be delivered in many seaports and freely stored on board the ship [32].

Taking this into account, the experiments were carried out on a specialized sea ship with deadweight of 9600 tons. The ship made transitions between ports, which provided for the possibility of replenishing alternative fuel supplies. The auxiliary power plant of the ship consisted of three diesel engines of the same type with the following characteristics:

– bore – 170 mm;
– stroke – 280 mm;
– speed – 900 rev/min;
– output range – 575 kW;
– specific fuel oil consumption – 193 g/(kWh).

During the operation of the diesel engine, RMB30 fuel was used, which complies with the international fuel standard ISO 8217 and has the following main characteristics:

– viscosity at 40 °C – 30 mm^2/s;
– density at 15 °C – 960 kg/m^3;
– sulfur content – 0.47 %.

RMB30 fuel is recommended for use in marine diesel engines that operate on a four-stroke cycle. The use of this fuel is possible in all operating modes of the diesel engine (including starting modes).

Biofuel B99.9 FAME with the following main characteristics was used as an alternative fuel:

– content of biodiesel fuel – 99.9 %;
– diesel fuel content – 0.1 %;
– diesel fuel class – Ultra-Low Sulfur Diesel fuel;
– sulfur content in diesel fuel – 0.03 %;
– viscosity at 40 °C – 20 mm^2/s;
– density at 15 °C – 870 kg/m^3.

Comparable values of viscosity and density of RMB30 fuel and B99.9 FAME biofuel ensured the creation of their stable fuel mixture [33]. The main component of the fuel mixture was RMB30 diesel fuel. The content of biofuel in the fuel mixture varied within 5–20 % of the total volume.

Preparation of fuel mixtures for marine diesel engines is possible in a cyclic or continuous way. In the first case, the equipment that ensures the preparation of the mixture operates periodically [34]. The fuel mixture prepared in this way is sent either to the diesel engine (to service tanks) or to spare tanks. With a continuous preparation method, the fuel mixture is immediately fed to the high-pressure fuel equipment and injected into the diesel cylinder. During the experiment, the fuel mixture of RMB30 diesel fuel and B99.9 FAME biodiesel fuel was prepared in a continuous way in accordance with the scheme shown in Fig. 1.

The operation of the fuel system was as follows.

From service tank 1, RMB30 diesel fuel through coarse filter 2 was supplied to fuel pumps 4 and then sent to diesel engines 5. Additional fuel purification was provided using fine filter 3. The fuel supply circuit to the first diesel engine did not change, the diesel engine was operated on RMB30 fuel and considered to be «control». In the circuit of the other two diesel engines, a biodiesel fuel tank B99.9 FAME 6, dispenser 7 and flow meter 9 were additionally installed. The required amount of biofuel in the fuel mixture was provided using microcontroller 8 belonged to the ship [35].

The efficiency of biofuel use was assessed according to environmental and economic criteria. The concentration of nitrogen oxides NO_X and the volumetric content of carbon monoxide CO in exhaust gases were taken as an environmental criterion. As an economic – specific effective fuel consumption be.

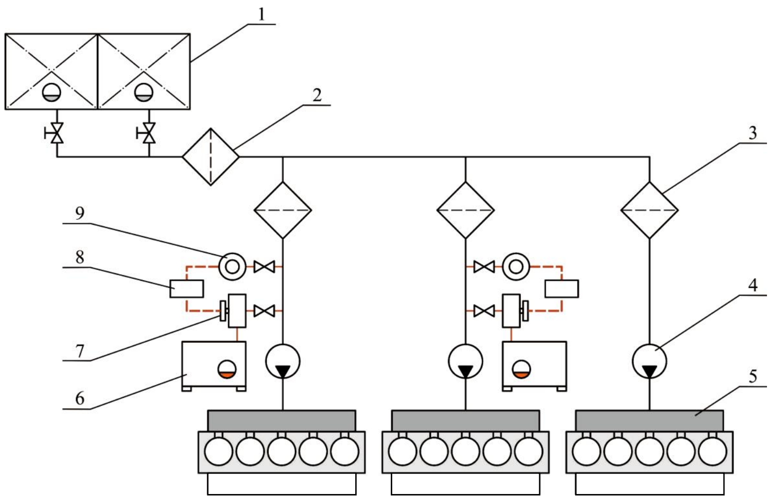

Fig. 1. Schematic diagram of the fuel system of 5H17/28 Hyundai Heavy Industries marine diesel engines: 1 – RMB30 diesel service tank; 2 – coarse fuel filter; 3 – fine fuel filter; 4 – fuel pump; 5 – diesel; 6 – service tank for biodiesel fuel B99.9 FAME; 7 – dispenser; 8 – microcontroller; 9 – flow meter

The concentration of nitrogen oxides NO_X and the volumetric content of carbon monoxide CO in exhaust gases were controlled using a gas analyzer Testo350XL (Germany). The gas analyzer allows measurements in the temperature range of –40–1200 °C. The Testo350XL gas analyzers meet the requirements of the Continuous Emission Monitoring System (CEMS) of the Environmental Protection Agency (EPA).

The analysis of the exhaust gases was carried out in the gas exhaust line at a distance of 10 m from the place where the gases from the gas turbocharger exited, which complies with the requirements of the NO_X Technical Code. The measurement error of NOX emission in the exhaust gases, performed by the Testo350XL gas analyzer, was ±1.0 %.

The specific effective fuel consumption b_e was determined using onboard measuring instruments – a flow meter installed on the fuel supply line to the high pressure fuel pump, as well as a timer, and was calculated from the dependence:

$$b_e = \frac{G_h}{N_{e\,\text{work}}},$$

where G_h – hourly fuel consumption, kg/h, determined by the expression:

$$G_h = \frac{V_f \rho}{t},$$

where V_f – the volume of fuel passed through the flow meter, m^3; ρ – the fuel density at the corresponding temperature, kg/m^3; t – the time during which the experiment was carried out in the corresponding mode of operation of the diesel engine, h; $N_{e\,\text{work}}$ – the diesel power, in different operating modes, kW. The $N_{e\,\text{work}}$ value was determined in the central control room of the engine room using electronic equipment.

The error in determining the specific effective fuel consumption did not exceed ±2.5 %.

At the time of the study, a «reference» diesel (using RMB30 fuel) and one or two others (using a mixture of RMB30 fuel and B99.9 FAME biofuel) were used to provide energy to consumers. Diesels, on which experimental studies were carried out, supplied power to permanent groups of consumers. In this case (depending on the modes under study), their power was 315, 375, 430 and 490 kW. This corresponded to a load of 55, 65, 75 and 85 % of the rated diesel power. The error in the value of the load during the transition of the diesel engine from one steady state to another did not exceed ±1.5 %.

Before the start of the experiment, all diesel engines had the same engine life of the fuel equipment, parts of the cylindrical group, motion bearings, as well as the same technical condition.

By switching groups of consumers, the operation of diesel engines was carried out at a constant load, which was necessary during the experiment. In the case of a change in the number of energy consumers and their power, the necessary load was redistributed to diesel engines that were not involved in the experiment. At the same time, the diesel engine on which the research was carried out continued to be operated at a constant load. In addition, during the experiment on a diesel engine, constant temperature conditions were maintained in the lubrication and cooling systems.

During the experiment, the diesel engine worked at a constant load for 1.0–1.5 hours, during which the main parameters were measured and the obtained values were averaged. This ensured the correctness of the research and the possibility of comparing measurements performed on different diesel engines.

6. Research results

The research was carried out during the ocean passage of the ship. The duration of the experiment was 7–8 hours. At the same time (due to the absence of cargo operations), the operation of the auxiliary power plant took place without abrupt changes in loads. Roll, trim and other external influences did not affect the measured parameters.

The results of the experiment to determine the concentration of nitrogen oxides NO_X and the volumetric content of carbon oxides CO in the exhaust gases, as well as the calculation of the specific effective fuel consumption b_e are given in Table 1.

The concentration of nitrogen oxides in the exhaust gases of marine diesel engines is regulated by the requirements of Annex VI MARPOL. According to these requirements, the Hyundai Heavy Industries 5H17/28 marine diesel engine belongs to the Tier II level. For such diesel engines, the NO_X concentration in the exhaust gases should not exceed the value determined by the expression:

$$NO_X \le 44 n^{-0.23}, \quad (1)$$

where n – the diesel shaft speed, rev/min.

For a 5H17/28 Hyundai Heavy Industries marine diesel engine, let's obtain:

$$NO_X \le 44 \cdot 900^{-0.23} = 9.20 \text{ kg/(kWh)}.$$

Let's note that under all modes and under any conditions of the experiment, the concentration of nitrogen oxides in exhaust gases did not exceed the value determined by expression (1). Thus, the operation of Hyundai Heavy Industries diesel engines 5H17/28 during the experiment was carried out in compliance with Annex VI MARPOL requirements [36].

For better visualization of the results obtained, according to the values of Table 1 the diagrams shown in Fig. 2.

Let's note that for the entire concentration range of B99.9 FAME biofuel mixed with RMB30 fuel, a decrease in NO_X and CO emissions in exhaust gases and an increase in the specific effective fuel consumption are observed.

Table 1

Experiment results

Diesel load, %	Fuel type				
	RMB30	RMB30+5 % biofuel	RMB30+10 % biofuel	RMB30+15 % biofuel	RMB30+20 % biofuel
Concentration of nitric oxide NO_X in exhaust gases, g/(kWh)					
55	7.72	6.92	6.22	6.12	6.51
65	7.94	7.18	6.32	6.22	6.74
75	8.32	7.42	6.43	6.24	7.01
85	8.68	8.02	6.56	6.37	7.28
Volume content of carbon monoxide CO in exhaust gases, %					
55	6.32	6.08	5.75	5.38	4.88
65	6.48	6.22	5.88	5.44	5.12
75	6.85	6.28	6.16	5.68	5.36
85	7.37	6.58	6.28	5.98	5.63
Specific effective fuel consumption b_e, g/(kWh)					
55	208	212	217	219	226
65	205	208	209	215	221
75	197	199	200	202	212
85	193	194	195	197	204

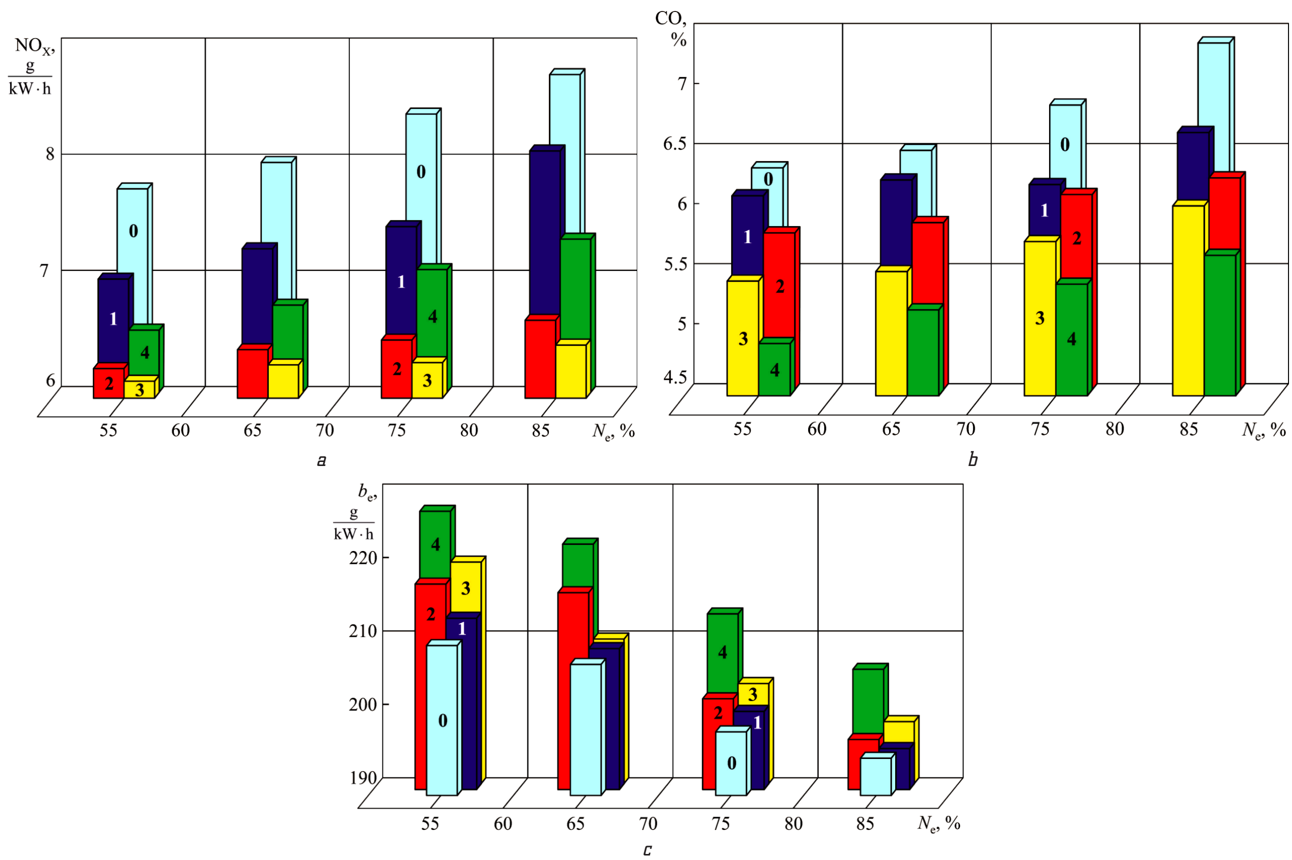

Fig. 2. Dependences of the performance of diesel engine 5H17/28 Hyundai Heavy Industries on the load when using fuel of different composition: *a* – the emission of nitrogen oxides; *b* – the volume content of carbon monoxide in exhaust gases; *c* – the specific effective fuel consumption; 0 – RMB30; 1 – RMB30+5 % biofuel; 2 – RMB30+10 % biofuel; 3 – RMB30+15 % biofuel; 4 – RMB30+20 % biofuel

Relative changes in the concentration of nitrogen oxides ΔNO_X and the volume content of carbon monoxide ΔCO in exhaust gases, as well as specific effective fuel consumption Δb_e were calculated by the expressions:

$$\Delta NO_X = \frac{NO_X^{RMB} - NO_X^{bio}}{NO_X^{RMB}} \cdot 100\ \%,$$

$$\Delta CO = \frac{CO^{RMB} - CO^{bio}}{CO^{RMB}} \cdot 100\ \%,$$

$$\Delta b_e = \frac{b_e^{bio} - b_e^{RMB}}{b_e^{bio}} \cdot 100\ \%,$$

where NO_X^{RMB}, NO_X^{bio} – the concentration of nitric oxide in the exhaust gases of a diesel engine during its operation on RMB fuel and a mixture with biofuel, g/(kWh); CO^{RMB}, CO^{bio} – the volumetric content of carbon monoxide in the exhaust gases of a diesel engine when it runs on RMB fuel and a mixture with biofuel, %; b_e^{RMB}, b_e^{bio} – the specific effective fuel consumption of a diesel engine during its operation on RMB fuel and a mixture with biofuel, g/(kWh).

The obtained values are summarized in Table 2, and also shown in the diagrams of Fig. 3.

The efficiency of using a mixture of biofuel and diesel fuel is expediently carried out by an integrated method. In this case, the main attention should be paid to reducing the emission of nitrogen oxides and increasing the specific fuel consumption. The emission of carbon oxides (due to its toxicity) is also an important indicator. However, at present, its meanings are not limited to normative documents and conventions. Therefore, this value should be attributed to an indirect indicator.

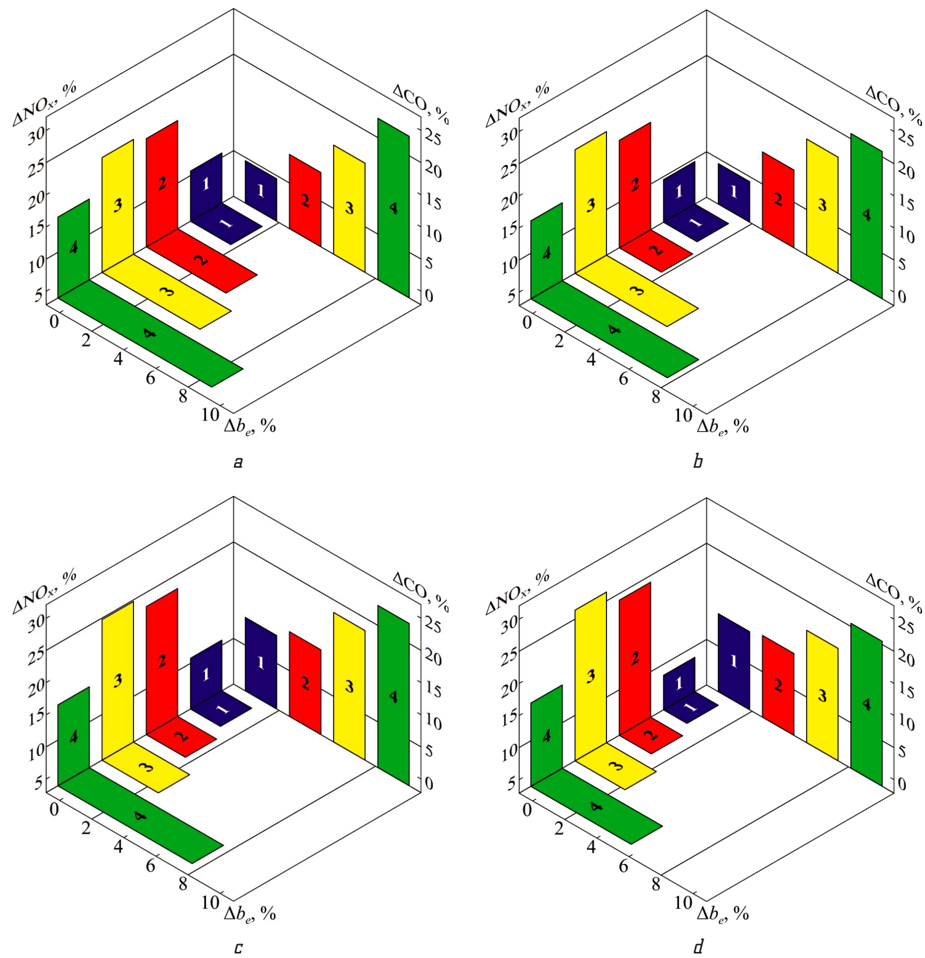

Fig. 3. Relative change in performance of diesel engine 5H17/28 Hyundai Heavy Industries when using fuel of different composition: *a* – load 55 %; *b* – load 65 %; *c* – load 75 %; *d* – load 85 %; 1 – RMB30+5 % biofuel; 2 – RMB30+10 % biofuel; 3 – RMB30+15 % biofuel; 4 – RMB30+20 % biofuel

Table 2

Change in the relative performance of a diesel engine

Diesel load, %	Fuel type			
	RMB30+5 % biofuel	RMB30+10 % biofuel	RMB30+15 % biofuel	RMB30+20 % biofuel
Reduction in the concentration of nitrogen oxides ΔNO_X in exhaust gases, %				
55	10.36	19.43	20.73	15.67
65	9.57	20.40	21.66	15.11
75	10.82	22.72	25.00	15.75
85	7.60	24.42	26.61	16.13
Reduction in the volume content of carbon monoxide ΔCO in exhaust gases, %				
55	3.80	9.02	14.87	22.78
65	4.01	9.26	16.05	20.99
75	8.32	10.07	17.08	21.75
85	10.72	14.79	18.86	23.61
Increase in specific effective fuel consumption Δb_e, %				
55	1.92	4.33	5.29	8.65
65	1.46	1.95	4.88	7.80
75	1.02	1.52	2.54	7.61
85	0.52	1.04	2.07	5.70

7. SWOT analysis of research results

Strengths. The use of fuel mixtures consisting of diesel fuel and biofuel improves the environmental performance of marine diesel engines. This is manifested in a decrease in the emission of toxic components of exhaust gases – nitrogen oxides and carbon oxides. This fact is especially relevant given the current requirements of international and national conventions that limit emissions of harmful emissions into the atmosphere.

The introduction of alternative types of fuel into the marine power industry helps to reduce the consumption of fuel of petroleum origin. Biofuel production is possible in a country limited by natural reserves of petroleum fuel. At the same time, the use of own fuel of non-oil origin reduces the energy dependence of the state on external countries and manufacturers.

Weaknesses. To use biofuel on existing ships, it is necessary to re-equip the fuel system. To perform such work, it is necessary to coordinate the technical design with the representatives of the Register, which carries out technical supervision of the ship and the ship's power plant.

Biofuel characteristics (viscosity, density, flash point) must be comparable to those of diesel fuel. This limits the possibility of using a different range of biofuel grades.

Opportunities. The use of biofuel as a component of the fuel mixture is possible for any marine diesel engines. The re-equipment of the ship's fuel system, as well as its further operation and control of work, can be carried out independently by the ship's crew, taking into account the developed technological scheme.

Threats. The variant of biofuel use proposed in the paper is of an applied nature and is based on practical experience. The navigation area of sea and river ships may exclude ports where it is possible to obtain biofuel. Taking into account this circumstance, diesel fuel reserves should be calculated in order to avoid a possible shortage of fuel on the ship.

8. Conclusions

1. In marine diesel engines with a power of up to 1000 kW, it is possible to use fuel mixtures, the basis of which (80–95 %) is diesel fuel, the rest is biofuel. It is advisable to create a fuel mixture immediately before it is supplied to the diesel cylinders. At the same time, with the help of a dosing device, the required amount of biofuel is introduced into the diesel fuel stream, and their further mixing is provided by a fuel pump.

2. Evaluation of the effectiveness of the use of a fuel mixture consisting of diesel fuel and biofuel, it is advisable to carry out according to environmental and economic criteria. As an environmental criterion, the emission of nitrogen oxides NO_X and carbon oxides CO with exhaust gases of a diesel engine is determined. As an economic one, the specific effective fuel consumption is calculated.

Tests performed on Hyundai Heavy Industries 5H17/28 marine medium-speed diesel engines in their operating load range of 55–85 % with a fuel mixture that included 80–95 % DMB diesel fuel and 5–20 % B99.9 FAME biofuel established:

a) the use of biofuels improves the environmental friendliness of marine diesel:

– by 7.6–26.61 % (depending on the diesel load and the content of biofuel in the fuel mixture), the emission of nitrogen oxides with exhaust gases is reduced;

– by 3.8–23.6 % (depending on the diesel load and the content of biofuel in the fuel mixture), the emission of carbon oxides with exhaust gases is reduced;

b) when using biofuel, there is an increase in the specific effective fuel consumption by 0.5–8.65 %, which reduces the efficiency of the diesel engine.

3. It is advisable to determine the optimal composition of the fuel mixture containing biofuel experimentally for each diesel load, taking into account environmental and economic performance indicators.

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