UDC 629.5
DOI: 10.15587/2706-5448.2023.290198

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# DEVELOPMENT OF METHOD FOR MANAGING RISK FACTORS FOR EMERGENCY SITUATIONS WHEN USING LOW-SULFUR CONTENT FUEL IN MARINE DIESEL ENGINES

*The operation process of marine diesel engines when using fuel with a sulfur content of no more than 0.1 % was chosen as the object of the study. Similar types of fuel are characterized by a lower auto-ignition temperature and higher calorific value. During combustion, this leads to an increase in the rate of fuel combustion and the degree of pressure increase during combustion, precisely because of this, the dynamic loads on the parts of the cylinder-piston group and diesel engine bearings increase. Also, this (due to the increase in temperature at the end of combustion) creates conditions for an increase in the concentration of nitrogen oxides in diesel exhaust gases. This (namely, the change in dynamic and thermal loads that occur during the use of fuels with a reduced sulfur content in marine diesel engines) leads to the occurrence of emergency situations. As a method of managing the risk of such emergency situations, the reconfiguration of the high-pressure fuel equipment, namely the change of the advance angles of the fuel supply, is proposed. The research was carried out on a vessel intended for the transportation of containers and on which a marine diesel engine 8K80ME-8.2-TII MAN-Diesel & Turbo was installed as the main engine. Combustion pressure, the degree of pressure increase during combustion, the temperature of exhaust gases, and the concentration of nitrogen oxides in exhaust gases were chosen as the indicators for evaluating the use and implementation of the proposed method. It has been experimentally proven that this results in an increase in the environmental sustainability of diesel operation by 3.61–10.97 %, an increase in thermal stability – up to 2.54 %, and an increase in dynamic stability – up to 4.82 %. This is due to the shift of the self-ignition and combustion process towards expansion and the corresponding decrease in pressure and temperature at the end of combustion. The most favorable use of this method is on modern diesel engines that have an electronic fuel injection control system, so they do not require mechanical reconfiguration of fuel pumps. Taking this into account, the method based on the change of fuel advance angles is defined as the one that provides management of the risk factors of emergency situations when using low-sulfur fuel in marine diesel engines.*

**Keywords:** *emergency situation, dynamic loads, environmental indicators, management method, sea transport, marine diesel, heat loads, risk factor.*

*Received date: 10.09.2023*
*Accepted date: 30.10.2023*
*Published date: 31.10.2023*

***How to cite***
*Sagin, S., Sagin, A. (2023). Development of method for managing risk factors for emergency situations when using low-sulfur content fuel in marine diesel engines. Technology Audit and Production Reserves, 5 (1 (73)), 37–43. doi: https://doi.org/10.15587/2706-5448.2023.290198*

## 1. Introduction

Sea transport is the main component of transport logistics, which ensures cargo flows between countries located on different continents [1, 2]. Transportation of finished products, raw materials, grain, oil and gas between South and North America, Asia, Africa and Europe is impossible without the use of sea vessels of various deadweight and purpose [3, 4]. The movement of modern sea vessels is provided by internal combustion engines, which are the most common heat engines and are the main element of ship power plants [5, 6].

The operation of marine internal combustion engines of sea and inland water transport vessels is carried out not only with maintaining the required power and meeting the requirements of manufacturers, but also with maintaining the environmental performance of their operation. The main environmental indicators of the operation of marine diesel engines are the concentration of sulfur oxides SOX and nitrogen oxides $NO_X$ in the exhaust gases [7, 8]. Their values are determined in accordance with the requirements of Annex VI of the International MARPOL Convention. At the same time, the limit values of $NO_X$ emissions (which correspond to Tier I, II or III levels) depend on the year the diesel engine was built and its rated speed. The limit values for $SO_X$ emissions are determined only by the sulfur content of the fuel [9, 10].

From 02/01/2020, the use of marine fuels with a sulfur content exceeding 0.5 % by weight is prohibited on sea and inland water transport vessels [11, 12]. Special ecological areas to limit emissions of sulfur oxides (Sulfur Emission Control Areas – SECAs) have also been defined. In these areas, it is permitted to use fuel with a sulfur content of no more than 0.1 % by weight. When ships operate in these areas or when crossing them, marine diesel engines are switched to operate on precisely these types of fuel. This conversion is carried out gradually, taking into account the volume of fuel in the supply tank, the sulfur content in the fuel and the operating power of the diesel engine. The operating time of a diesel engine using fuel with low sulfur content depends on the speed characteristics of the vessel, hydrometeorological conditions of the passage, time spent in the SECAs zone and ranges from several hours (when the vessel is in the ecological regions of Northern Europe) to several days (when moving along the coast of North America).

One of the main difficulties that arise when converting diesel engines to operate using low-sulfur fuel is the following. A decrease in the sulfur content in the fuel leads to a decrease in its density, viscosity, auto-ignition temperature and an increase in the calorific value of the fuel (due to a proportional increase in the hydrogen and carbon content in the fuel) [13, 14].

Under the same injection process conditions, fuels that have a lower auto-ignition temperature and a higher calorific value are characterized by a higher end-of-combustion temperature $T_z$. This is due to a decrease in the auto-ignition delay angle, an increase in the combustion onset angle, and greater efficiency of the combustion process in the top dead center region [15, 16].

Provided that the fuel ignites earlier, the amount of fuel that burns to top dead center increases. This leads to an increase in the rate of fuel combustion and the degree of pressure increase during combustion:

$$\lambda = p_z / p_c, \tag{1}$$

where $p_z$, $p_c$ – maximum combustion pressure and pressure at the end of compression, MPa.

This phenomenon is most negative for two-stroke diesel engines, which are characterized by an increased mass of crank mechanism parts. In this regard, shock loads on crosshead and crank bearings increase sharply [17, 18].

Determining $T_z$ by measurement is impossible due to the dynamic change in temperature in a diesel cylinder; therefore, calculation models are used to estimate its values [19, 20]. The simulation results for MAN-Diesel & Turbo diesel engines of the same cylinder diameter $D$, but different in piston stroke $S$, are presented in Table 1.

**Table 1**

Modeling results

| Diesel and its characteristics | Fuel characteristics | | Temperature at the end of combustion, K |
|---|---|---|---|
| | sulfur content, % | calorific value, kJ/kg | |
| K80ME | 0.48–0.50 | 41580 | 1869 |
| $D$=0.8 m | 0.4–0.45 | 41864 | 1878 |
| $S$=2.3 m | 0.05–0.09 | 42180 | 1896 |
| L80ME | 0.48–0.50 | 41596 | 1825 |
| $D$=0.8 m | 0.4–0.45 | 41899 | 1839 |
| $S$=2.592 m | 0.05–0.09 | 42241 | 1858 |
| S80ME | 0.48–0.50 | 41695 | 1815 |
| $D$=0.8 m | 0.4–0.45 | 41888 | 1836 |
| $S$=3.056 m | 0.05–0.09 | 42240 | 1851 |
| G80ME | 0.48–0.50 | 41595 | 1758 |
| $D$=0.8 m | 0.4–0.45 | 41918 | 1762 |
| $S$=3.72 m | 0.05–0.09 | 42260 | 1788 |

A seemingly insignificant increase in temperature at the end of combustion $T_z$ when switching from one type of fuel to another leads to a cumulative effect due to the inertia of thermal processes. At the same time, the thermal load on the diesel exhaust system increases. The «hidden» negative consequences of increasing temperature $T_z$ also include an increase in the emission of nitrogen oxides $NO_X$, which are formed in accordance with the high-temperature Zeldovich mechanism.

Thus, meeting the requirements of Annex VI MARPOL and converting marine diesel engines to operate on low-sulfur fuel (which is mandatory when seagoing vessels are in SECAs) increases the risks of the following emergency situations:

- increased dynamic loads in the crank mechanism;
- increase in temperature tension;
- increased emissions of nitrogen oxides.

Solutions to these problems have been proposed in various ways. In order to reduce dynamic loads, compressed air is supplied to the under-piston space of the diesel engine, as well as a reduction in the cyclic fuel supply and a corresponding decrease in the diesel rotation speed [21, 22]. However, these methods reduce diesel power and vessel speed.

To reduce temperature stress, additional water injection is used into the cylinder and exhaust system of the diesel engine. Using these methods, it is possible to reduce the temperature of the exhaust gases by 20–50 °C, but this increases the likelihood of sulfur corrosion of cylinder liners, pistons and exhaust valves [23, 24].

To reduce nitrogen oxide emissions, various methods are used, including exhaust gas recirculation, installation of scrubbers, filters and catalysts [25, 26]. These methods provide a 30–90 % reduction in the concentration of nitrogen oxides in exhaust gases, but require significant financial investments and maintenance of additional equipment [27, 28]. In addition, their use is limited in the event of a deterioration in the navigation situation during a sea crossing [29, 30].

In this regard, *the aim of research* is to develop a method for managing risk factors for emergency situations (in particular, a sharp increase in dynamic loads and an increase in nitrogen oxide emissions) when using fuel with low sulfur content in marine diesel engines. At the same time, all energy and environmental performance indicators of the diesel engine must be maintained within the recommended limits.

## 2. Materials and Methods

*The object of research* is the process of operating marine diesel engines using fuel whose sulfur content does not exceed 0.1 %.

The studies were carried out on a specialized sea vessel designed for transporting containers. The main engine on the vessel was a marine diesel engine 8K80ME-8.2-TII MAN-Diesel & Turbo with the following main characteristics:

- cylinder diameter – 0.8 m;
- piston stroke – 2.3 m;
- shaft rotation speed – 104 rev$^{-1}$;

– number of cylinders – 8;
– rated power – 35600 kW.

The diesel engine was operated outside SECA using RMG380 fuel with sulfur content of 0.48 %, as well as RME180 fuel; in SECA – on DMA fuel with a sulfur content of 0.055 %. The main characteristics of the fuels are given in Table 2.

**Table 2**

Main characteristics of marine fuels

| Characteristic | RMG380 | RME180 | DMA |
|---|---|---|---|
| Carbon content, % | 82.7 | 83.3 | 83.8 |
| Hydrogen content, % | 10.6 | 10.7 | 11.1 |
| Sulfur content, % | 0.48 | 0.42 | 0.055 |
| Density at 15 °C, kg/m$^3$ | 989 | 961 | 855 |
| Viscosity at 50 °C, mm$^2$/s | 380 | 380 | 12 |
| Flash point, °C | 83 | 76 | 66 |
| Self-ignition temperature, °C | 201 | 195 | 106 |
| Calorific value, kJ/kg | 41160 | 42010 | 42340 |
| Area of possible use | only outside SECAs | | any areas, including SECAs |

The diesel operating parameters were monitored using the Doctor diagnostic system, which allows the values to be determined with an accuracy of ±0.5 %.

The emission of nitrogen oxides from exhaust gases was determined using a Testo gas analyzer, and the measurement error did not exceed 0.5 %.

## 3. Results and Discussion

Combustion pressure $p_z$, exhaust gas temperature $t_g$, concentration of nitrogen oxides in exhaust gases $NO_X$, as well as the degree of pressure increase during combustion $\lambda$ were taken as indicators that were evaluated during the operation of the 8K80ME-8.2-TII MAN-Diesel & Turbo diesel engine on different types of fuel. The research results are given in Table 3.

Visualization of the results in Table 3 is shown in Fig. 1.

**Table 3**

Research results

| Fuel brand | Combustion pressure $p_z$, MPa | Exhaust gas temperature $t_g$, °C | Concentration of nitrogen oxides in exhaust gases $NO_X$, g/(kW·h) | The degree of pressure increase during combustion $\lambda$ |
|---|---|---|---|---|
| RMG380 | 14.22 | 374 | 12.9 | 1.324 |
| RME180 | 14.28 | 381 | 13.3 | 1.329 |
| DMA | 14.45 | 394 | 13.75 | 1.335 |

The results of the studies confirm the previously stated thesis that the transfer of marine diesel engines to operate on fuel with low sulfur content (from RMG380 fuel to RME180 fuel and to DMA fuel) increases dynamic and thermal loads, and also worsens the environmental performance of the diesel engine. All this increases the risk of emergency situations when converting marine diesel engines to operate on fuel with low sulfur content [31, 32].

As a method by which it is possible to control these processes, re-adjustment of the fuel supply phases was chosen, namely, changing the advance angle of fuel supply to the diesel cylinders. The optimal values of these angles (at which the combustion process occurs with maximum heat release when the piston is at top dead center) are determined during bench tests of the diesel engine. In this case, tests are carried out for the nominal operating mode of the diesel engine and on fuel, the brand of which is assumed to be the main one when operating the diesel engine. Thus, the likelihood of diesel operation on fuels with low sulfur content, as well as in a mode other than the nominal one, is not taken into account. In this regard, there are no recommendations regarding optimal fuel supply angles for various diesel operating modes, as well as in the case of using different types of fuel. Determination of these angles is only possible during direct operation of the diesel engine, and all requirements and recommendations for its operation must be observed [33, 34].

In connection with the above, the further technology of experimental research consisted of the following.

After preparing the fuel system of the 8K80ME-8.2-TII MAN-Diesel & Turbo diesel engine for operation in SECA (namely, the full consumption of RMG380 fuel with a sulfur content of 0.48 % and filling the supply tanks with DMA fuel with sulfur content of 0.055 %), the fuel supply system was reconfigured in diesel cylinders.

For cylinders Nos. 1 and 8, the value of the fuel supply advance angles (at which the diesel engine was operated using RMG380 fuel) remained unchanged and amounted to $\theta$: −3°, −2°, −1°, −1°, −2°, −3° CRA (crankshaft rotation angle).

For cylinders Nos. 2, 3, 4, 5, 6, 7, new fuel supply advance angles $\theta$ were established: −3°, −2°, −1°, −1°, −2°, −3° CRA, respectively. Setting the same fuel supply advance angles in two cylinders (in the first and eighth, second and seventh, third and sixth, fourth and fifth) increased the array of results obtained, increased the accuracy of measurements and made it possible to perform corrective actions in case of discrepancies.

During the study, for each of the cylinders, the maximum combustion pressure $p_z$, the pressure at the end of compression $p_c$, the average indicator pressure $p_i$ and the exhaust gas temperature $t_g$ were monitored.

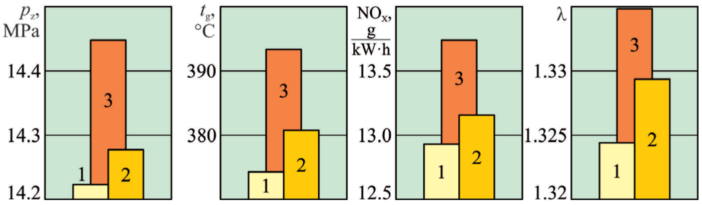

**Fig. 1.** Changes in the performance of the marine diesel engine 8K80ME-8.2-TII MAN-Diesel & Turbo when using different fuels: 1 – RMG380; 2 – RME180; 3 – DMA

For each of the given parameters, average values were calculated:

$$\left.\begin{array}{l} p_z^{md}=\left(p_z^1+p_z^2+\ldots+p_z^8\right)/8;\; p_c^{md}=\left(p_c^1+p_c^2+\ldots+p_c^8\right)/8; \\ p_i^{md}=\left(p_i^1+p_i^2+\ldots+p_i^8\right)/8;\; t_g^{md}=\left(t_g^1+t_g^2+\ldots+t_g^1 8\right)/8; \end{array}\right\} (2)$$

as well as its deviation from the average value:

$$\left.\begin{array}{l} \Delta p_z^1=\frac{\left|p_z^1-p_z^{md}\right|}{p_z^1}\cdot 100\ \%,\ \Delta p_z^2=\frac{\left|p_z^2-p_z^{md}\right|}{p_z^2}\cdot 100\ \%,\ \ldots\ \Delta p_z^8=\frac{\left|p_z^8-p_z^{md}\right|}{p_z^8}\cdot 100\ \%; \\ \Delta p_c^1=\frac{\left|p_c^1-p_c^{md}\right|}{p_c^1}\cdot 100\ \%,\ \Delta p_c^2=\frac{\left|p_c^2-p_c^{md}\right|}{p_c^2}\cdot 100\ \%,\ \ldots\ \Delta p_c^8=\frac{\left|p_c^8-p_c^{md}\right|}{p_c^8}\cdot 100\ \%; \\ \Delta p_i^1=\frac{\left|p_i^1-p_i^{md}\right|}{p_i^1}\cdot 100\ \%,\ \Delta p_i^2=\frac{\left|p_i^2-p_i^{md}\right|}{p_i^2}\cdot 100\ \%,\ \ldots\ \Delta p_i^8=\frac{\left|p_i^8-p_i^{md}\right|}{p_i^8}\cdot 100\ \%; \\ \Delta t_g^1=\frac{\left|t_g^1-t_g^{md}\right|}{t_g^1}\cdot 100\ \%,\ \Delta t_g^2=\frac{\left|t_g^2-t_g^{md}\right|}{t_g^2}\cdot 100\ \%,\ \ldots\ \Delta t_g^3=\frac{\left|t_g^3-t_g^{md}\right|}{t_g^3}\cdot 100\ \%, \end{array}\right\} (3)$$

where $p_z^{md}, p_c^{md}, p_i^{md}, t_g^{md}$ – the average values of combustion pressure, compression pressure, average indicator pressure and exhaust gas temperature; $p_z^1, p_z^2, \ldots p_z^8$ – combustion pressure in the 1st, 2nd, ... 8th cylinders, respectively; $p_c^1, p_c^2, \ldots p_c^8$ – compression pressure in the 1st, 2nd, ... 8th cylinders, respectively; $p_i^1, p_i^2, \ldots p_i^8$ – average indicator pressure in the 1st, 2nd, ... 8th cylinders, respectively [35, 36]; $t_g^1, t_g^2, \ldots t_g^8$ – exhaust gas temperatures in the 1st, 2nd, ... 8th cylinders, respectively [37, 38]; $\Delta p_z^1, \Delta p_z^2, \ldots \Delta p_z^8$ – deviation of combustion pressure from the average value in the 1st, 2nd, ... 8th cylinders, respectively; $\Delta p_i^1, \Delta p_i^2, \Delta p_i^8$ – deviation of compression pressure from the average value in the 1st, 2nd, ... 8th cylinders, respectively; $\Delta p_c^1, \Delta p_c^2, \Delta p_c^8$ – deviation of the average indicator pressure from the average value in the 1st, 2nd, ... 8th cylinders, respectively; $\Delta t_g^1, \Delta t_g^2, \ldots \Delta t_g^8$ – deviation of the exhaust gas temperature from the average value in the 1st, 2nd, ... 8th cylinders, respectively [39, 40].

In addition, the value of the degree of pressure increase during combustion $\lambda$ was determined, and the emission of nitrogen oxides from $NO_X$ exhaust gases was monitored. The diesel performance indicators were recorded for a load of $0.85N_{enom}$ (where $\lambda=35600$ kW is the rated power). The results of the experiment are given in Table 4.

For better visualization of the obtained values, based on the data (Table 4), diagrams were constructed (Fig. 2), which reflects changes in diesel performance indicators under various conditions for setting up fuel equipment.

Let's also note that during the experiments, the deviation of the controlled parameters (combustion pressure $p_z$, compression pressure $p_c$, average indicator pressure $p_i$, exhaust gas temperature $t_g$) did not exceed the values regulated by the operating rules. The $NO_X$ concentration in the exhaust gases in all operating modes did not exceed the maximum possible value, which for diesel engines classified as Tier II in accordance with the requirements of Annex VI MARPOL is 14.4 g/(kW·h) [8, 12, 26].

The presented results indicate the possibility of managing the risk of emergency situations associated with the use of fuels with low sulfur content by changing the fuel supply advance angles.

The amount of margin of environmental, thermal and dynamic stability of marine diesel engines in the case of their transfer to operation on fuel with reduced sulfur content is determined by the following expressions:

– margin of environmental sustainability:

$$\Delta NO_X=\frac{NO_X^{Tier}-NO_X^i}{NO_X^{Tier}}\cdot 100\ \%; \qquad (4)$$

– thermal stability margin:

$$\Delta t_g=\frac{t_g^{\max}-t_g^i}{t_g^{\max}}\cdot 100\ \%; \qquad (5)$$

– dynamic stability margin:

$$\Delta\lambda=\frac{\lambda^{\max}-\lambda^i}{\lambda^{\max}}\cdot 100\ \%, \qquad (6)$$

where $NO_X^{Tier}$ – the maximum value of nitrogen oxide emissions in accordance with Tier Annex VI MARPOL; $t_g^{\max}$, $\lambda^{\max}$ – respectively, the maximum values of the exhaust gas temperature and the degree of pressure increase during combustion, obtained during the experiment; $NO_X^i$, $t_g^i$, $\lambda^i$ – respectively, the values of the concentration of oxides in the exhaust gases, the temperature of the exhaust gases and the degree of pressure increase during combustion in different diesel cylinders, obtained during the experiment.

The values obtained in this way are presented in Table 5.

For better visualization, the results obtained are presented in the form of a diagram in Fig. 3.

**Table 4**

Experiment results

| Parameter | Cylinder number | | | | | | | | Average value |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | |
| Combustion pressure, $p_z$, MPa | 14.45 | 14.38 | 14.23 | 14.05 | 14.03 | 14.21 | 14.36 | 14.47 | 14.27 |
| Deviation from the average value, $\Delta p_z$, % | 1.23 | 0.75 | 0.29 | 1.58 | 1.73 | 0.44 | 0.61 | 1.36 | – |
| Compression pressure, $p_c$, MPa | 10.82 | 10.78 | 10.77 | 10.78 | 10.76 | 10.82 | 10.8 | 10.82 | 10.79 |
| Deviation from the average value, $\Delta p_c$, % | 0.29 | 0.07 | 0.17 | 0.08 | 0.26 | 0.29 | 0.11 | 0.29 | – |
| Average indicator pressure, $p_i$, MPa | 1.995 | 1.987 | 2.012 | 2.02 | 1.996 | 1.985 | 2.014 | 2.018 | 2.00 |
| Deviation from the average value, $\Delta p_i$, % | 0.42 | 0.82 | 0.43 | 0.82 | 0.37 | 0.93 | 0.53 | 0.72 | – |
| Exhaust gas temperature, $t_g$, °C | 394 | 388 | 382 | 378 | 375 | 385 | 390 | 394 | 386 |
| Deviation from the average value, $\Delta t_g$, °C | 8 | 2 | 4 | 8 | 11 | 1 | 4 | 8 | – |
| The degree of pressure increase during combustion $\lambda$ | 1.335 | 1.334 | 1.321 | 1.303 | 1.304 | 1.313 | 1.329 | 1.337 | – |
| Emission of nitrogen oxides from exhaust gases, $NO_X$, g/(kW·h) | 13.75 | 13.62 | 13.21 | 12.82 | 12.85 | 13.12 | 13.51 | 13.88 | – |

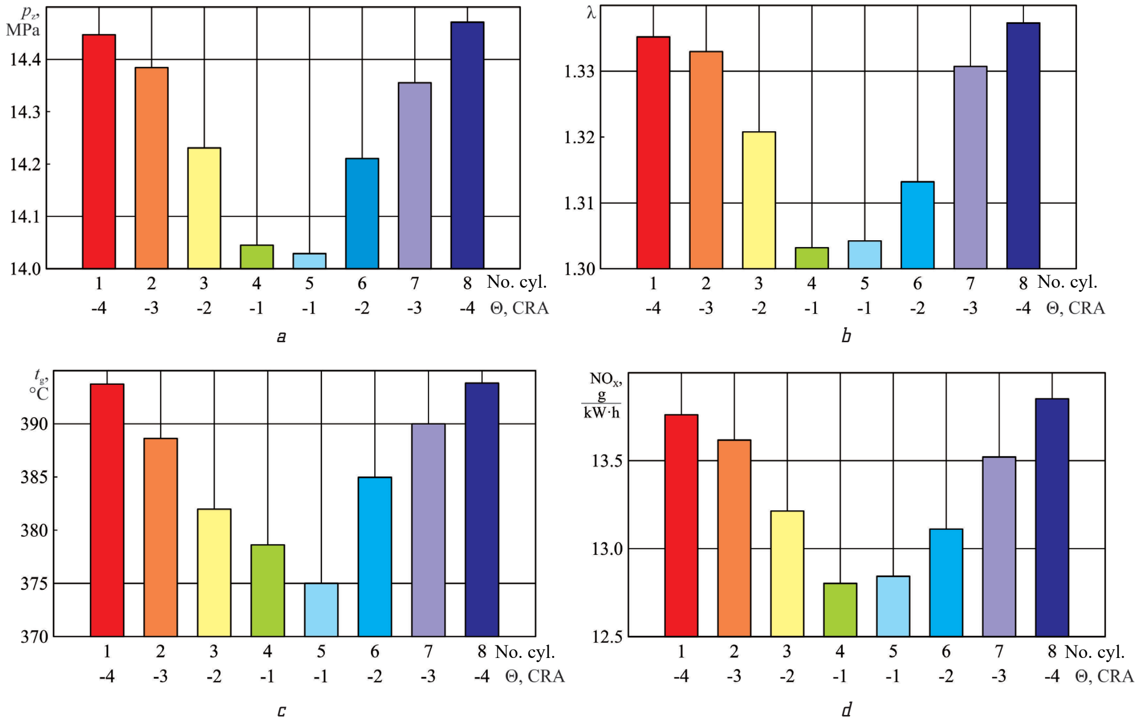

**Fig. 2.** Change in performance indicators of the marine diesel engine 8K80MC-8.2-TII at different fuel supply advance angles θ:
*a* – combustion pressure; *b* – exhaust gas temperature; degree of pressure increase during combustion; *c* – concentration of nitrogen oxides in exhaust gases; *d* – degree of pressure increase during combustion

**Table 5**

Determination of diesel stability margin

| Index | CRA | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | –4 | –3 | –2 | –1 | –1 | –2 | –3 | –4 |
| Environmental sustainability, % | 4.51 | 5.42 | 8.26 | 10.97 | 10.76 | 8.89 | 6.18 | 3.61 |
| Thermal stability, % | 0.14 | 0.257 | 1.20 | 2.54 | 2.50 | 1.79 | 0.58 | 0 |
| Dynamic stability, % | 0 | 1.52 | 3.05 | 4.06 | 4.82 | 2.28 | 1.028 | 0 |

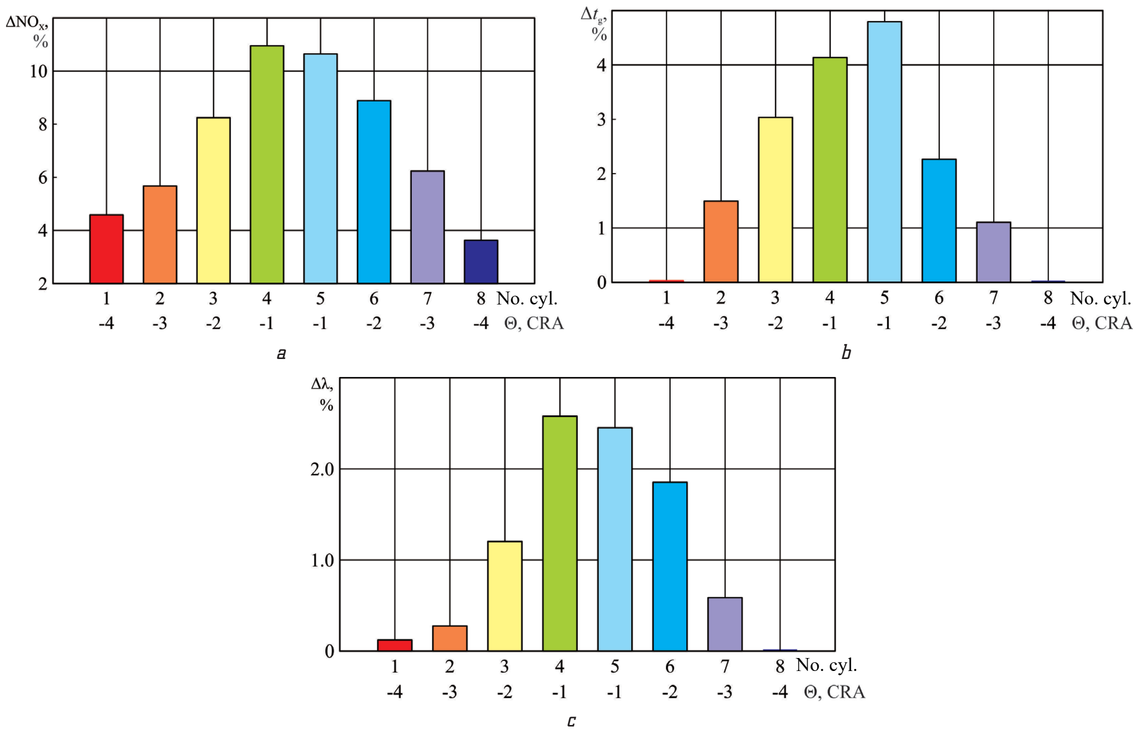

**Fig. 3.** Stability of the marine diesel engine 8K80MC-8.2-TII operation at different fuel supply advance angles θ:
*a* – environmental; *b* – thermal; *c* – dynamic

The conduct of all experiments was agreed upon with the technical department of the shipping company, which manages the ship and its power plant. During the experiments, all operating parameters of the 8K80MC-8.2-TII MAN-Diesel & Turbo marine diesel engine were monitored and maintained within the recommended ranges.

The practical significance of the results of the research is the possibility of their use in both two and four-stroke diesel engines that have an electronic fuel injection control system. The use of the developed method is especially relevant when ships are in special ecological areas, the number and boundaries of which are constantly increasing and expanding.

The limitations of the proposed method include the presence of «critical» fuel supply angles, angles at which stable self-ignition and combustion of fuel decreases. Determining these angles is only possible experimentally, and for each diesel engine. In this case, it is necessary to take into account the design features of the diesel engine, as well as the operational characteristics of the fuel.

The declaration of martial law in Ukraine significantly reduced communication opportunities between researchers and increased the time required for solving assigned tasks, but did not suspend testing on sea vessels.

Further research will be aimed at determining the range of possible operating modes of marine diesel engines and fuel equipment, in which their trouble-free operation is guaranteed if the proposed method is used.

## 4. Conclusions

It is shown that in the case of the operation of sea and inland water transport vessels in SECAs ecological areas, there is a need to convert marine diesel engines to fuel with low sulfur content. At the same time, the intensity of fuel combustion increases, thermal and dynamic loads increase, and the environmental performance of the diesel engine worsens. All this increases the risk of emergency situations.

As a method of managing risk factors for emergency situations when using fuel with low sulfur content in marine diesel engines, it is possible to use re-regulation of high-pressure fuel equipment (in particular, to ensure a change in the fuel supply advance angles).

Experiments carried out on a marine diesel engine 8K80MC-8.2-TII MAN-Diesel & Turbo confirmed that in the case of transferring a diesel engine from RMG380 fuel (with sulfur content of 0.48 %) to DMA fuel (with sulfur content of 0.55 %) by changing the feed advance angles fuel possible:

- ensure a reduction in combustion pressure from 14.45 MPa to 14.03 MPa;
- achieve a reduction in the exhaust gas temperature from 394 °C to 375 °C;
- reduce the degree of pressure increase during combustion from 1.335 to 1.303;
- reduce the emission of nitrogen oxides from exhaust gases from 13.75 g/(kW·h) to 12.82 g/(kW·h).

This provides an increase:

- environmental sustainability – by 3.61–10.97 %;
- thermal stability – up to 2.54 %;
- dynamic stability – up to 4.82 %.

Re-adjustment of high-pressure fuel equipment must be carried out when sea and inland water transport vessels are in SECAs. In this case, it is necessary to ensure preliminary preparation of the fuel system for the use of fuel with low sulfur content.

### Conflict of interest

The authors declare that they have no conflict of interest in relation to this study, including financial, personal, authorship, or any other, that could affect the study and its results presented in this article.

### Financing

The study was conducted without financial support.

### Data availability

The manuscript has no associated data.

### Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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