ASSESSMENT OF MARINE DIESEL ENGINES PERFORMANCE BASED ON CARBON AND NITROGEN OXIDES CONTENT IN EXHAUST GASES

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Keywords: Marine diesel engines, operating conditions, combustion dynamics indicators, carbon, nitrogen oxides, regularities

Abstract. The paper presents the analysis of the regularities of the carbon and nitrogen oxides content in the exhaust gases of marine diesel engines (MDEs) of fishing industry fleet, taking into account the features of their operation (changes of hydrometeorological conditions and technical performance). The factors cause decrease in excess air coefficient during combustion, deterioration in the quality of fuel atomization, mixture formation and combustion.

A special feature of mixture formation and combustion processes in MDEs with a volumetric method of mixture formation is the separation of the combustion chamber into a series of macro-volumes, each of which receives fuel from the corresponding nozzle opening. At the same time, the concentrations of fuel and air in terms of jets length and sections of are uneven. The smallest drops are located on the surface of fuel jets and, first of all, are inhibited in the dense and hot environment of the working fluid.

The temperature in the combustion zone reaches 2600-2900 K and warms up the fuel contained in the inner layers during the lack of oxygen. As a result, carbon is formed, and at the same time in the surface layers - nitrogen oxides.

It is shown that in order to simulate the influence of operating factors, the indicators describing the dynamics of combustion of fuel and those that explicitly take into account the effect of structural and operational factors are suitable. A difference in the regularities of the change in carbon emissions with exhaust gases for engines with supercharging and without it is focused. Dependencies have been proposed for modeling carbon emissions and nitrogen oxides when a supercharged engine is subjected to a load (regulatory) characteristic. The possibility of using indicators for diagnosing the technical condition of internal combustion engine is shown.

1 INTRODUCTION

The engines of the fishing fleet vessels operate in different regions of the World Ocean which are specific in hydrometeorological conditions and MDE technical conditions changes. It results in decrease in the excess air factor during combustion, increased fuel consumption, carbon/ nitrogen oxides and other harmful components emissions, increased thermal stress of cylinder piston group [1].

Engines with volumetric (jet) method of mixture formation are mostly used on the vessels of the fishing industry fleet. In the case fuel jets surface contains the smallest drops which are primarily inhibited, evaporated and ignited. The flame temperatures reach 2600-2900 K [2] at which intensive formation of nitrogen oxides occurs. Approaching the axis and the front of the jet the droplet diameters increase and the amount of air that is available decreases. Consequently, under the influence of the heat flux, pyrolysis of fuel droplets with hydrogen separation and carbon formation occurs [2],[3],[4].

To assess the quality of spraying and mixing, there are several approaches. The first calculates the number and diameter of the fuel droplets, their distribution in the fuel jet. The disadvantage of this approach, in our opinion, is the excessive complexity and the absence of an indicator characterizing the surface area of the heat and mass exchange with the surrounding air charge. In the second, the ratio of the surface area of fuel jets to the amount of fuel contained in them is proposed [5]:

$$K_{p\Sigma} = F_{\phi\Sigma} / g_{ц} \tag{1}$$

where – «F» is the surface area of the fuel jets at the end of the injection process, m2; gц – cyclic fuel supply, kg.

This indicator is applied to both the fuel jet as a whole and its individual components.

With the deterioration of the combustion process, accompanied by an increase in its duration, the temperature of the parts of the CPG(cylinder piston group) increases significantly [6]. Therefore, under the influence of operational factors that lead to an increase in the average indicator pressure, a decrease in the excess air factor during combustion, an extension of the combustion process (and heat transfer taking into account radiation), the calorific intensity increases. Thus, we should add an increase in calorific intensity due to excessive fuel consumption (caused by increased resistance to vessel movement and the deviation of the combustion process from that one specified by the manufacturer [1]) to the known categories of hazards discovered by the scientists of the Admiral Makarov State University of Maritime and Inland Shipping [7],

One of the indicators for assessing the technical performance of the diesel engine can be the content of products of incomplete combustion and nitrogen oxides in its exhaust gases.

The purpose of this paper is to develop an integrated algorithm for estimating the overall technical performance of the engine for the content of incomplete combustion products and nitrogen oxides in the exhaust gases.

For example, [5],[8], it is established that carbon emissions depend on a set of factors including: the thermal characteristics of the fuel used, the state of the air charge in the cylinder at the time of fuel supply, the geometric characteristics of the atomizer nozzle, the characteristics of the fuel supply processes, combustion. These factors are taken into account by the following complexes, the exponents in which are obtained taking into account the work of Professor A.S. Lyshevsky [9]who investigated a large array of experimental data on the characteristics of spraying of fuel:

$$B=\left(\frac{\mu_{\text{сп}}}{\mu_{\text{сэ}}}\right)^{1,42}\cdot\left(\frac{d_{\text{сп}}}{d_{\text{сэ}}}\right)^{1,05}\cdot\left(\frac{P_{\text{fп}}-P_{\text{цп}}}{P_{\text{fэ}}-P_{\text{цэ}}}\right)^{0,71}\cdot\left(\frac{\rho_{\text{Тп}}}{\rho_{\text{Тэ}}}\right)^{1,05}\cdot$$
$$\left(\frac{\sigma_{\text{э}}}{\sigma_{\text{п}}}\right)^{0,37}\left(\frac{\mu_{\text{п}}}{\mu_{\text{э}}}\right)^{0,32}\frac{P_{\text{цэ}}}{P_{\text{цп}}}\frac{T_{\text{цп}}}{T_{\text{цэ}}}\frac{J_{\text{сї}}}{J_{\text{сэ}}}\frac{g_{\text{цэ}}}{g_{\text{цп}}};\qquad(2)$$

$$C=\frac{tg\gamma_n(1/\cos\gamma_n+tg\gamma_n)}{tg\gamma_{\text{э}}(1/\cos\gamma_{\text{э}}+tg\gamma_{\text{э}})};\qquad(3)$$

$$Д=\frac{\tau_{инд.п}}{\tau_{инд.э}}\frac{\tau_{впр.э}}{\tau_{впр.п}}\left(\frac{\tau_{Zn}-0,5\tau_{впр.п}}{\tau_{Zэ}-0,5\tau_{впр.э}}\right)^{1,6};\qquad(4)$$

where «d_c» and «J_c» – are the diameter and number of nozzle openings in the atomizer, «μ_c» – is its flow coefficient, «P_f» – is the average fuel pressure, «P_c» and «T_c» – are the mean pressure and temperature of the air charge in the cylinder during the fuel supply, «ρ», «μ» and «σ» – are the density, viscosity and coefficient of surface tension of fuel, «$g_{ц}$» – cyclic fuel supply, «γ» – cone angle of fuel jet (torch), «τ_{ind}», «$\tau_{впр}$» and «τ_z» - duration of ignition delay, fuel supply and combustion respectively, for the calculation of which are designed the formula [5].

It is established that [10] for atmospheric engines, the dependence of the carbon content in the exhaust gases as a function of the product of complex indicators (BCD) is linear. For example, for an engine of 1NVD24 [10]:

$$c = -0.123\ (B * C * D) + 0.1844 \qquad (5)$$

where «c» - is the specific carbon emission in g/(kW*h).

However, in some high – speed internal combustion engines, for example 8-12/12 [8], in modes close to the rated one, the deviation from the linear dependence is observed due to the increase in the length of the fuel jets and part of the cyclic fuel supply to the walls of the combustion chamber.

It should be noted for supercharged engines: as the load decreases, the dependence of the form (5) also deviates from the linear one, starting from a relative load of less than 50%. For example, in the MAN D 2866 engine (6 cylinders, 4 – stroke, bore 128 mm, stroke 155 mm) installed on the sailing training ship Krusenstern as a diesel generator, the deviation of the type (5) from the linear characteristic starts at a load of 50% [8]. The fact is explained by a significant deterioration in the spraying process accompanied by the enlargement of the droplets.

For medium-speed engine with a higher supercharging and cylinder power of about 500 kW [11], carbon emissions increase linearly in the range of loads from the nominal to 0.75, after which the emissions increase with varying degrees of intensity. The reason for this change is a deterioration of the quality of fuel atomization in systems with a mechanical injection pump from the crankshaft, since the geometric characteristics of fuel-injection pump elements are optimized for loads close to the nominal one. Therefore, for the internal combustion supercharged engines it is necessary to supplement the index (BCD), characterizing the dynamics of combustion, with a calculated diameter of the fuel droplets within the investigated and nominal modes:

$$c = f\,(BCD * d_r) \qquad (7)$$

If the droplets average arithmetic diameter is set (Fig. 1), the carbon emission curve is somewhat smoothed out.

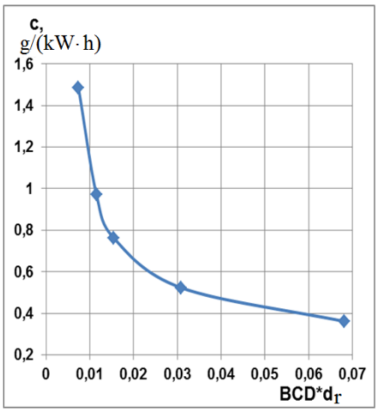

Figure 1. Dependence of the carbon content in the exhaust gases of the medium – speed marine diesel engines with a cylinder power of 500 kW taking into account the arithmetic average diameter of the droplets

Application as a generalizing diameter d30 or d32 [9]type practically does not change the dependence (Figure 1):

$$c = 0.064\ (BCD * d_r)\ 0.618 \qquad (6)$$

The linearization of a function can be obtained by its logarithm:

$$Ln\ (c) = -0.618\ Ln\ (BCD * d_r)\ -2.749 \qquad (7)$$

The reliability of $R^2 = 0.974$ for the functions (6) and (7).

As it can be seen from the graph, the lower the quality index of the process flow the higher the carbon emission in the exhaust gases. With a decrease in the indicator ($BCD * d_r$) by 10%, the carbon content increases by an average of 8.5%, and at loads less than 50% - by 9.3%.

As follows from equations (2) - (4), the decrease in the BCD index can occur due to a deviation in the operation of each of the factors included in them.

The regularity of the change in the content of nitrogen oxides in the exhaust gases of the medium-speed engine with a cylinder power of 500 kW at 720 rpm in the entire range of load characteristics is a line of two sections, each of which is close to a straight line (Figure

2). When the load decreases from nominal to 50% (the corresponding change in the index (BCD * d_r) from 0.0682 to 0.0239) is accompanied by a 14% reduction in nitrogen oxide emissions (from 8.7 to 7.5 g/(kW*h)). Further reduction in load and index (BCD * d_r) results in a significant increase in NOx emissions.

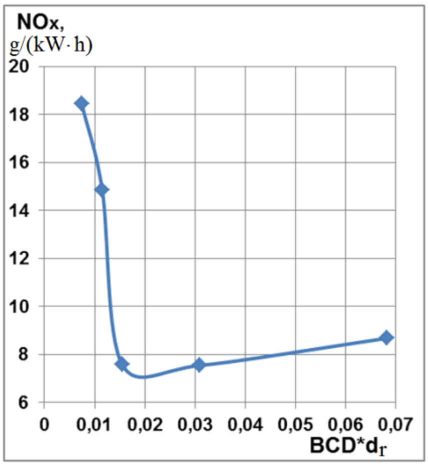

Figure 2. Dependence of nitrogen oxide emissions on the complex of BCD * workflow indicators

The graph of figure 2 is approximated by two straight lines. On the load section, 10-50%

$$NOx = -1342.5\ (BCD * d) + 29.031 \tag{8}$$

At the load area of 50-100%

$$NOx = 1.145\ (BCD * d) + 0.0328 \tag{9}$$

The use of a gas analyzer with functions for determining the concentration of carbon and nitrogen oxides will allow us to find the boundary between the normal technical state and the beginning of its deterioration.

The enlarged algorithm for assessing the technical performance of diesel includes the following operations:

1. For each model of the diesel engine, at the manufacturer's test bench or during delivery trials, the dependences of the change in the carbon content and nitrogen oxides on the screw characteristics or in a series of load characteristics (for several values of n = const) for the main engines are found. For diesel generators, several modes are considered with respect to the load characteristic with a nominal speed of rotation. The dependence of the cyclic fuel supply and the position of the load indicator is established.
2. Comparison of the calculated dependences with the experimental data obtained during bench tests or delivery trails for the passport technical condition and experimental conditions; equations of the form (8) - (11) are made. The comparison allows to obtain the discrepancy coefficients.

3. During the operation, carbon emissions and nitrogen oxides are monitored and compared with the dependencies obtained earlier (paragraph 2) taking into account the discrepancy coefficients.
4. The computational modeling on the computer the values of the complexes of the parameters B, C and D (expressions (2) - (4)) are calculated, as well as the temperature of the exhaust gases and the maximum combustion pressure when the parameters of the external environment change (barometric pressure, temperature and relative humidity) , technical condition of the fuel equipment (average fuel pressure, coking and wear of the nozzle openings), pressurization and gas exchange systems (pressure and charge air temperature, final compression pressure) and cylinder-piston group(final compression pressure).
5. Carbon and nitrogen oxides in exhaust gases are measured in operation and compared with previously obtained regularities (clause 2). In the case of exceeding the values of carbon concentrations and nitrogen oxides the active factors entering into expressions (2) - (4) are analyzed.
6. If the parameters that depend on hydrometeorological conditions are different the corresponding changes in the values of complexes B, C, D and emission concentrations are calculated under the condition of the passport technical condition of the engine. If the calculated value of the influence of hydrometeorological conditions compensates for the change in the amount of emissions the elements of the diesel are in a satisfactory condition. If not, we proceed to the next diagnostic procedure
7. The technical condition of the fuel equipment is checked either with the help of the measuring complex or in its absence by changing the additional estimated parameters - the temperature of the exhaust gases and the maximum combustion pressure.

CONCLUSION

The analysis of the results of experimental studies on the estimation of carbon emissions and nitrogen oxides with exhaust gases of marine diesel engines with supercharging and without boosting is carried out. It was found that in engines without a boost, for example, NVD24, the dependence of carbon emissions on the BCD index is linear. In engines with supercharged linear dependence is valid in the range of loads from 50 to 100%. With further reduction of the load there is an intensive increase in emissions due to the fact that the geometric characteristics of the elements of the fuel-injection pump are selected by the manufacturing plants for the modes close to the operational and full load. Therefore, in partial modes these parameters become overestimated that worsens the quality of the processes of spraying, mixture formation and combustion and determines the intensive growth of harmful emissions. In order to take into account this circumstance, the indicator that characterizes the flow of spraying, mixing and combustion processes is supplemented taking into account the representative diameter of the fuel droplets. As the ratio of arithmetic mean diameters of droplets at the current mode of operation of the diesel and at full load mode is accepted.

As a result, the dependencies of carbon emissions are rectified, that indicates the adequacy of the accepted BCD * d_r indicator which has been tested in several sizes of diesel engines. Its application to the current indicators and methods of diagnosis will allow more accurate assessment of the technical condition of internal combustion engine. An algorithm for diagnosing the engine by its exhausted gas composition has been developed.

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