Reduced emission of nitrogen oxides by the diesel engine running on methanol and methyl ether of rapeseed oil

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Abstract. Recently the use of alternative fuels obtained from renewable resources has become a focus of great interest in motor transport industry. An important requirement which alternative fuels have to meet is reduced level of toxic emission into environment. The alternative fuels considered in the article that follows are methanol and methyl ether of rapeseed oil. The paper deals with specific features of nitrogen oxides formation by the diesel engine 2F10.5/12.0 running on these fuels under various loads and speed rates. Theoretical and experimental studies have shown a considerable decrease in toxic emissions, nitrogen oxides in particular.

At present the strictest regulation of toxic emissions by automobiles and tractors is becoming increasingly necessary throughout the world because the values sometimes exceed maximum concentration limits by ten folds, which causes a considerable damage to environment, wildlife, and vegetation [1-7]. A diesel engine emits as many as 280 various substances into the atmosphere, many of them are toxic and give rise to severe illnesses [8-13]. Thus, getting into the human body, the particles of nitrogen oxides cause dysfunction of lungs and bronchi and, when reacting with water, they form nitric and nitrous acids bringing about acid rains.

For decades, a lot of scientists around the world have been trying to solve this problem by improving the operation of the engine, as well as by using new alternative renewable fuels. Such fuels include methyl ether of rapeseed oil (RME) and methyl alcohol (methanol) [13-26]. The use of pure rapeseed oil as diesel fuel is somewhat complicated, as it possesses increased viscosity and coking properties, while its ether does not have these disadvantages, at the same time, its cetane number is higher as compared to diesel fuel (DF), which is favourable for complete combustion of this type of fuel. To increase economic efficiency of the ether, it can be used in combination with a cheaper fuel – methanol. The cetane number of methanol is not big enough for its self-ignition, so, it will be necessary to use a small portion of ether as initiator. In addition, methanol has a low thermal value, so fuel consumption will be larger. However, its cost is much lower as compared to DF, besides, both of these fuels (methanol and RME) are renewable, that is why using them will decrease the demand for oil fuel and improve environmental performance of the engine.

The Department of Thermal Engines, Vehicles and Tractors is engaged in the research aimed at reducing toxicity of diesel exhausts, and in particular – reducing nitrogen oxides emission by means of using the fuels mentioned above. The object of this study was the engine 2F10.5/12.0 and the alternative fuels were fed by means of dual-fuel system (DFS).

This study deals with specific features of nitrogen oxides formation in various load modes of the engine running on methanol and RME. For this purpose, it was necessary to obtain load characteristics...
of the engine operated in two specific speed rates: at the rate of rotation corresponding to the nominal operating mode (n = 1800 min\(^{-1}\)) and the mode of maximum torque (n = 1400 min\(^{-1}\)). In the process of reading these characteristics, NO\(_x\) content in exhaust gases was being measured in every operating mode of the engine.

Alongside with experimental studies on NO\(_x\) emissions there were theoretical calculations of nitrogen oxides formation in the same operating modes of the engine. The calculations were made by using the elaborated mathematical model of nitrogen oxides formation based on thermal mechanism proposed by Ya.B. Zeldovich. The base values for calculation are indicated pressure and mean pressure of gases in the engine cylinder. The graphs that are peculiar to nominal operating mode are presented in figure 1.

![Figure 1. Indicated pressure and mean temperature under the nominal operating mode (p_e = 0.588 MPa and n = 1800 min\(^{-1}\)): --- diesel process; ---- dual-fuel.](image)

Studying these diagrams one can note that using these alternative fuels results in some decrease in the pressure and temperature of gases in the engine cylinder, while the process of combustion moves to the expansion line, which, according to thermal mechanism of nitrogen oxides formation, cannot but reduce NO\(_x\) emission.

The results of experimental studies and theoretical calculations of nitrogen oxides formation under various loading modes corresponding to nominal rotation rate (n = 1800 min\(^{-1}\)) are presented in figure 2. In the diagrams one can see that the experimental and calculation data show a considerable decrease in NO\(_x\) emission as the result of using the alternative fuels, virtually throughout the entire range of loads, as compared to diesel process. According to the experimental data, under minimal load (p_e = 0.115 MPa) the value of nitrogen oxides concentration (\(r_{\text{NOx, exp.}}\)) is 270 ppm for diesel process, while for the alternative fuels it is ~120 ppm. There is 2.25-fold decrease. As the load increases to become nominal (p_e = 0.588 MPa), these values are 762 and 401 ppm respectively, the decrease being 47.4\%. Only under maximum load (p_e = 0.692 MPa) there is some growth of \(r_{\text{NOx}}\) which is due to higher pressure and temperature in the engine cylinder as compared to diesel process.

The calculated curves of nitrogen oxides formation at the exit from the cylinder indicate a similar dependence. Likewise, one can observe a considerable decrease in \(r_{\text{NOx, calc.}}\) almost under every operating mode of the engine except maximum load. Comparing the calculated and experimental data indicates their high repeatability, which confirms the appropriateness of the selected model of nitrogen oxides formation.
Figure 2. Dependence of nitrogen oxides concentration on the load and the angle of crankshaft rotation in the engine 2F 10.5/12.0 under the nominal operating mode:
- diesel process;
- - dual-fuel system.

Figure 3. Dependence of nitrogen oxides concentration on the load and the angle of crankshaft rotation in the engine 2F 10.5/12.0 in the mode of maximum torque:
- diesel process;
- - dual-fuel system.

Figure 3 presents similar diagrams corresponding to the engine operating at the rate of rotation \( n = 1400 \text{ min}^{-1} \). At this speed rate one can observe the decrease in the emission of nitrogen oxides under nearly all loads, except the maximal one, which is confirmed by both – the calculated and experimental data.
It should be noted that, according to the experimental data, under the loading mode $p = 0.115 \text{ MPa}$ the value of nitrogen oxides concentration ($r_{\text{NOx exp}}$) in diesel process is 400 ppm, while it equals to 150 ppm when using the alternative fuels, the decrease being 2.67-fold. In the mode of maximum torque ($p = 0.594 \text{ MPa}$) the emission of NOx is reduced by 33.5 %. As the diagrams show, the repeatability of the calculated and experimental data is quite high.

Thus, it is possible to achieve a considerable reduction in nitrogen oxides emission by the diesel engine 2F 10.5/12.0 when using two kinds of fuel—methanol and RME. It is mostly due to the fact that the peak of pressure and temperature in the cylinder moves to the right of top dead centre to the expansion line. It is possible to confirm experimentally and by means of calculation that formation and decomposition of nitrogen oxides chiefly occurs when the gases in the engine cylinder expand and take more volume.

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