Improving the environmental performance of the diesel engine fueled by methanol and methyl ether of rapeseed oil

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Abstract. Research aimed at reducing harmful emissions from diesel engines into the atmosphere throughout the world is of great current importance for its further introduction in transport industry. The article considers the issues related to the use of renewable alternative fuels – methanol and methyl ether of rapeseed oil, as well as the reduction in nitrogen oxide emissions by applying these fuels. The paper presents the comparative results of experimental findings (the data obtained as the result of bench testing) and theoretical ones. It has been noted that nitrogen oxide emissions (NO\textsubscript{x}) reduce by 47.4 %, when the engine is operated under nominal conditions, while at maximum torque they reduce by 33.5%.

Due to considerable growth of the world prices for crude oil and persistent toughening of regulations on toxic emissions into the atmosphere, more and more scientists throughout the world have to search for alternative types of fuel [1-13]. In order to be energetically self-sufficient, a lot of countries are trying to find not just alternative but renewable fuels. Fortunately, modern science possesses all means to solve this problem. In particular, owing to big areas of arable land it is possible to obtain, by means of cultivation and further processing, a completely renewable fuel – rapeseed oil [14-20]. The use of rapeseed oil as a fuel is complicated by some factors, one of them is increased viscosity, therefore, at low temperatures of environment, this kind of fuel has to be heated, otherwise, it will not be able to get through a fuel supply system into an engine cylinder. Consequently, the best solution for this problem is to use not pure rapeseed oil, but its methyl ether (RME). Physical and chemical characteristics of RME ( cetane number, viscosity, density etc.) are virtually similar to those of petrodiesel [21-27]. In order to achieve economic efficiency of this fuel, it can be used in combination with another renewable fuel – methyl alchhol. The cetane number of methanol is not big enough for its self-ignition, so, simultaneous supply of both fuels makes it possible to solve this problem.

In line with the above, bench tests of 2F 10.5/12.0 engine equipped with dual-fuel system and operating on methanol and RME have been conducted at the premises of the Department of Thermal Engines, Vehicles and Tractors, Vyatka State Agricultural Academy.

At the first stage of bench testing it is necessary to determine the optimal adjustment specifications of the engine, particularly – to find the best combination of fixer advance angles of fuel injection (FAA). When choosing the optimal FAA one should bear in mind that this adjustment has a considerable effect on toxicity of exhaust gases, on formation of nitrogen oxides in particular.

The article presents the test results and theoretical studies of the influence of FAA on nitrogen oxides emission by diesel engine 2F 10.5/12.0 running on methanol and RME with dual-fuel system.
To find the optimal fixer advance angles experimentally, the crankshaft angles were set at 26º, 30º, 34º, 38º to the top dead centre (TDC) for each kind of fuel. Therefore, 16 combinations of FAA were tested. It should be noted that the bench tests were carried out in two specific modes – under nominal conditions, the torque and pressure being equal to n=1800 min\(^{-1}\), \(p_e=0.588\) MPa respectively, and in the mode of maximum torque, \(n=1400\) min\(^{-1}\), \(p_e=0.594\) MPa. By means of data selection and approximation we found out dependences of volumetric concentration of nitrogen oxides \(r_{NOx}\) on advance angles of methanol and RME injection \((\Theta_{met} and \Theta_{RME})\) in the form of polynomials.

Under nominal conditions the dependence of volumetric concentration of NO\(_x\) on fixer advance angles can be presented by this equation:

\[
r_{NOx} = -0.084 \cdot \Theta_{RME}^2 \cdot \Theta_{met}^2 + 5.28 \cdot \Theta_{RME}^2 \cdot \Theta_{met} + 5.54 \cdot \Theta_{RME} \cdot \Theta_{met}^2 - 81 \cdot \Theta_{RME}^2 - 89.22 \cdot \Theta_{met}^2 - 346 \cdot \Theta_{RME} \cdot \Theta_{met} + 5266 \cdot \Theta_{RME} + 5527 \cdot \Theta_{met} - 83465;
\]

(1)

where 
\(NO_x\) – volumetric concentration of nitrogen oxides, ppm;  
\(\Theta_{RME}\) – advance angle of RME injection, \(^{\circ}\) crankshaft rotation to TDC;  
\(\Theta_{met}\) – advance angle of methanol injection, \(^{\circ}\) crankshaft rotation to TDC.

Determination coefficient in such a case is 0.989. The graph of the dependence obtained is presented in figure 1.

Figure 1. The influence of fixer advance angles on nitrogen oxides emission produced by diesel engine 2F 10.5/12.0 running on dual-fuel system in the standard operation mode (n=1800 min\(^{-1}\), \(p_e=0.588\) MPa)

Figure 2. The influence of fixer advance angles on nitrogen oxides emission produced by diesel engine 2F 10.5/12.0 running on dual-fuel system in the mode of maximum torque (n=1400 min\(^{-1}\), \(p_e=0.594\) MPa)
Figure 2 demonstrates the dependence of volumetric concentration of nitrogen oxides on fixer advance angles in the mode of maximum torque. The equation describing this dependence is presented by the following polynome:

\[
\begin{align*}
    r_{NOx} &= 3597 \cdot \Theta_{RME}^3 \cdot \Theta_{met}^3 - 0.72 \cdot \Theta_{RME}^3 - 0.3 \cdot \Theta_{met}^3 - 0.46 \cdot \Theta_{RME}^2 \cdot \Theta_{met}^2 + \\
    &+ 17.6 \cdot \Theta_{RME}^2 \cdot \Theta_{met} + 19 \cdot \Theta_{RME}^2 \cdot \Theta_{met}^2 - 140 \cdot \Theta_{RME}^2 - 227 \cdot \Theta_{met}^2 - 830 \cdot \Theta_{RME} \cdot \Theta_{met} + 8344 \cdot \Theta_{RME} + 11021 \cdot \Theta_{met} - 124153.
\end{align*}
\]

(2)

Considering the given correlations between the volumetric concentration of nitrogen oxides and fuel injection advance angles one can see that, generally, earlier injection of both of these alternative fuels results in the increased formation of nitrogen oxides. Such correlation behaviour can be explained by the fact that with larger fixer advance angles of alternative fuels injection, the maximum gas pressure in the engine cylinder and maximum mean temperature begin to increase, which results, in turn, in greater intensity of nitrogen oxides formation.

However, choosing the optimal fixer advance angles it is necessary to take into account the effects of this adjustment on the economic performance of the engine. With that in mind, it was decided to choose the crankshaft angles of \(\Theta_{RME}=34^\circ\) and \(\Theta_{met}=34^\circ\) to top dead centre. Such adjustment of fuel injection equipment helps to achieve the most efficient performance of the engine and, as it is shown in figures 1 and 2, moderate toxicity of exhaust gases. According to the test data, when the engine is running on alternative fuels, \(r_{NOx}\) is equal to 401 ppm under nominal operating conditions, which is by 47.4\% lower than \(r_{NOx}\) of a diesel-fueled production engine. At maximum torque, \(r_{NOx}\) is 582 ppm, which is by 33.5\% lower as compared to the diesel process.

Thus, experimental studies on exhaust toxicity have shown a considerable decrease in nitrogen oxides emission as the result of using alternative fuels, while the adjustment of fixer advance angles makes it possible, if necessary, to achieve a still greater decrease in the emission of these substances.

Apart from bench testing, theoretical studies of nitrogen oxides formation in the engine cylinder were also made. The obtained test data on \(r_{NOx}\) emissions allow us to make the assumption that in the process of nitrogen oxides formation the thermal mechanism prevails. The adjustment characteristic shows the increased formation of nitrogen oxides following the growth of pressure and gas temperature in the engine cylinder due to larger fixer advance angles.

The mathematical model of nitrogen oxides formation which was elaborated on the basis of the model proposed by Ya.B. Zeldovich makes it possible to calculate \(r_{NOx}\) taking into consideration the chemical composition of the alternative fuels. Notably, calculating the process of nitrogen oxides

![Figure 3. Theoretical studies on nitrogen oxides emission produced by diesel engine](image-url)
formation is based on the data of mean temperature, pressure, and heat emission obtained by means of processing indicator diagrams.

As a result, it became possible to obtain theoretical curves of NO\textsubscript{x} volumetric concentration in the function of crankshaft rotation at various fixer advance angles. The obtained graphs for some FAA in the nominal operation mode are presented in figure 3.

The calculation data on formation of nitrogen oxides also showed the growth of r\textsubscript{NOx} with larger fixer advance angles for both alternative fuels. This confirms the verity of the hypothesis made and predominance of thermal mechanism of NO\textsubscript{x} formation when the engine is running on methanol and RME with dual-fuel system. It should be also noted that the curves presented in figure 3 demonstrate the decline in the intensity of forming nitrogen oxides when the engine is running on methanol and RME as compared to diesel process at all given fixer advance angles.

It is possible to draw a conclusion that early injection of alternative fuels results in the increase in the pressure and temperature of gases in the engine cylinder and, consequently, NO\textsubscript{x} concentration rises, which is confirmed by calculations presented in figure 3. On the other hand, later injection of methanol and RME, vice versa, causes the shift of entire combustion process to the expansion line, which is certain to decrease the temperature in the engine cylinder and, therefore reduce NO\textsubscript{x} emissions. In view of this, it can be concluded that thermal mechanism of NO\textsubscript{x} formation predominates when the engine is running on alternative fuels, which is confirmed by the results of experimental and theoretical studies.

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