Characteristics of biofuel combustion in a diesel engine

A V Fominykh and V N Kopchikov
Department of Thermal Engines, Vehicles and Tractors, Vyatka State Agricultural Academy, 610017, Kirov, October prospect, 133, Russian Federation
E-mail: anfilatov001@mail.ru

Abstract. In recent years, energy independence from petroleum fuel has been of considerable interest in agriculture. In fact, occasional tightening of standards on toxic emissions combined with rising prices for diesel fuel, force scientists to look for alternative fuels. In this article, such fuels are represented by methyl alcohol, as the main fuel, and rapeseed oil methyl ether, as the fuel that is needed for the ignition of alcohol. The paper shows the characteristics of combusting these fuels in the diesel engine 2F 10.5/12.0 under various loading conditions when using a dual fuel system. The graphs of the indicator pressure and roughness of the combustion process during the operation of a diesel engine at a frequency corresponding to the nominal operation mode and maximum torque are presented. The article presents the analysis of the obtained diagrams and conclusions on the use of the above mentioned fuels in diesel engines.

One of the main tasks facing the world science is to develop new alternative types of fuel that are intended to replace conventional petroleum fuels as well as to reduce toxic emissions into the air basin [1-24]. In the most of farm machinery diesel engines are used for power supply. When diesel fuel is combusted, a large amount of toxic agents is released into the air [25-57]. Consequently, the urgent task today is to replace conventional petroleum fuels with alternative ones. When opting for alternative fuels, the main advantage is their renewability, since raw materials are limited. It should be also noted that physical and chemical properties of alternative fuels must not be inferior to those of diesel fuel [57-69]. Taking that into account, attention should be paid to such fuels as methyl alcohol (methanol) and rapeseed methyl ester (RME).

Since methanol in comparison with diesel fuel has a lower calorific value (19665 kJ/kg versus 42530 kJ/kg), its consumption during combustion is significantly higher. In addition, methanol has quite a low cetane number (3 vs 45), in contrast to diesel fuel, so its self-ignition in the diesel cylinder is impossible. However, this fuel has several essential advantages. For example, during the combustion of alcohol, much fewer toxic agents such as nitrogen oxides and soot are emitted because there is no emission of intermediate components that later produce aromatic and acetylene hydrocarbons contributing to the formation and further growth of soot particles. Another advantage of methanol is its low cost, as it can be obtained from food and agricultural waste, wood processing by-products, as well as from various gaseous fuels.

The methyl ester of rapeseed oil is very similar as to its characteristics to petroleum diesel fuel. For example, its cetane number is 51 and its calorific value is 37200 kJ/kg, which is 12% lower as compared with diesel fuel values, and therefore its consumption will be somewhat bigger. However, if it is used as ignition fuel, and methyl alcohol as the main fuel, a dual fuel system (DFS) being installed on the engine, the consumption of RME will decrease significantly. This type of fuel is also renewable. It is
produced on the basis of rapeseed oil and methyl alcohol. All the components are quite cheap to obtain and do not require high-tech equipment. In addition, the fuel obtained from rapeseed oil produces much fewer toxic substances during combustion because of the presence of oxygen in its composition. Thus, the alternative fuels presented above are a worthy substitute for petroleum diesel fuel.

In view of this, the Department of Heat Engines, Automobiles and Tractors of the Vyatka State Agricultural Academy carried out research on the peculiarities of the combustion process in the cylinder of a diesel engine operating on the proposed alternative fuels. The research object was a 2F 10.5/12.0 diesel engine. To feed methanol and RME, as ignition fuel, simultaneously, this engine was equipped with a dual fuel system, including an additional fuel pump, an additional set of injectors, as well as fuel pipes, a fuel tank and filters.

To study the characteristics of the combustion process, this paper presents indicator diagrams, as well as diagrams that characterize the rate of pressure increase (the roughness of the combustion process). The described dependencies were obtained when working at various load and speed modes of the engine.

Figure 1 shows comparative indicator diagrams obtained for the engine operating under various load conditions and rated speed $n=1800 \text{ min}^{-1}$. The presented diagrams were obtained when operating under load conditions corresponding to the average effective pressure $p_e$ equal to 0.115, 0.230, 0.346, 0.461, 0.588 and 0.692 MPa.

From this diagram, one can observe how the increase in the diesel engine loading affects the growth of the maximal pressure of gases in the cylinder. It can be noticed that when the maximum load $p_e=0.692$ MPa is reached, there is a significant jump in the indicator gas pressure. Such a sharp jump in the maximal gas pressure is probably due to a significant increase in the rate of combusting the mixture of methanol-air because of its enrichment with an increase in the cyclic feed of alcohol.

Considering the effects of alternative fuels on the roughness of the combustion process under various load modes of diesel operation (figure 2) , we can also observe a sharp jump in the maximal rate of pressure build-up $(dp/d\varphi)_{\text{max}}$ with increasing the loading up to $p_e=0.692$ MPa.
Figures 3 and 4 present similar diagrams, but they are typical for the engine operation at the speed corresponding to the maximum torque mode \( n=1400 \text{ min}^{-1} \). From figure 3, we can observe a more significant rise in the maximum gas pressure after a load increase at this speed mode. Operation of the engine at a frequency of \( n=1400 \text{ min}^{-1} \) is also characterized by higher rates of roughness of the combustion process at all load modes in comparison with the frequency of \( n=1800 \text{ min}^{-1} \).

Figure 2. Comparative diagrams of combustion process roughness at \( n=1800 \text{ min}^{-1} \).

Figure 3. Comparative indicator diagrams at \( n=1400 \text{ min}^{-1} \).
Thus, analyzing the indicator diagrams and diagrams of combustion roughness at various load and speed modes allows us to make the following practical conclusions. The increased loading of the engine is accompanied by an increase in the cyclic alcohol supply, since the cyclic portion of the ignition fuel is fixed. Due to increasing the amount of supplied methanol, the methanol-air mixture is enriched, which thereafter increases the rate of its combustion. This causes a significant rise in the maximal gas pressure in the diesel cylinder and the roughness of the combustion process under high load conditions. However, these indicators do not exceed the permissible values typical for the tested engine.

References
[1] Toigonbaev S K 2017 Education, Science and Humanities Academic Research Conference 380-400
[2] Likhanov V A and Lopatin O P 2018 IOP Conf. Series: Materials Science and Engineering 457 012011
[3] Romanyuk V, Likhanov V A and Lopatin O P 2018 Theoretical and Applied Ecology 3 27-32
[4] Kumar A N, Kishore P S, Raju K B, Kasianantham N and Bragadeswaran A 2019 Environmental Science and Pollution Research 26(7) 6652-76
[5] Lopatin O P 2020 IOP Conf. Series: Materials Science and Engineering 862 062087
[6] Anfilatov A A and Chuvashov A N 2020 IOP Conf. Series: Materials Science and Engineering 862 062064
[7] Marchuk A, Likhanov V A and Lopatin O P 2019 Theoretical and Applied Ecology 3 080-6
[8] Rajkumar S, Thangaraja J 2019 Fuel 240 101-18
[9] Anfilatov A A and Chuvashov A N 2020 Journal of Physics: Conf. Series 1515 022035
[10] Likhanov V A and Lopatin O P 2019 Journal of Physics: Conf. Series 1399 055016
[11] Skryabin M L and Likhanov V A 2020 IOP Conf. Series: Materials Science and Engineering 734 012075
[12] Likhanov V A and Lopatin O P 2019 Journal of Physics: Conf. Series 1399 055020
[13] Chuvashov A N and Chuprakov A I 2019 Journal of Physics: Conf. Series 1399 055085
[14] Likhanov V A and Rossokhin A V 2020 IOP Conf. Series: Materials Science and Engineering 862 062046
[15] Likhanov V A, Lopatin O P and Yurlov A S 2019 Journal of Physics: Conf. Series 1399 055026
[16] Anfilatov A A and Chuvashov A N 2020 Journal of Physics: Conf. Series 1515 042048
[17] Likhanov V A and Lopatin O P 2020 *IOP Conf. Series: Earth and Environmental Science* **421** 072018
[18] Anfilatov A A and Chupashev A N 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 062069
[19] Anfilatov A A 2020 *Journal of Physics: Conf. Series* **1515** 042049
[20] Lopatin O P 2020 *IOP Conf. Series: Earth and Environmental Science* **421** 072019
[21] Likhanov V A, Kozlov A N and Araslanov M I 2020 *IOP Conf. Series: Materials Science and Engineering* **734** 012211
[22] Likhanov V A and Rossokhin A V 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 062047
[23] Likhanov V A and Lopatin O P 2017 *Thermal Engineering* **64**(12) 935-44
[24] Skryabin M L 2020 *IOP Conf. Series: Earth and Environmental Science* **421** 072012
[25] Lopatin O P 2020 *Journal of Physics: Conf. Series* **1515** 042021
[26] Chupashev A N and Chuprakov A I 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 062089
[27] Likhanov V A and Lopatin O P 2020 *Journal of Physics: Conf. Series* **1515** 052002
[28] Likhanov V A and Lopatin O P 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 062014
[29] Kopchikov V N and Fominykh A V 2020 *Journal of Physics: Conf. Series* **1515** 042028
[30] Likhanov V A and Anfilatov A A 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 032048
[31] Anfilatov A A and Chupashev A N 2020 *Journal of Physics: Conf. Series* **1515** 042052
[32] Lopatin O P 2020 *Journal of Physics: Conf. Series* **1515** 042009
[33] Devetyarov R R and Chupashev A N 2020 *Journal of Physics: Conf. Series* **1515** 042080
[34] Likhanov V A and Lopatin O P 2019 *Ecology and Industry of Russia* **23**(9) 60-5
[35] Chupashev A N, Chuprakov A I and Anfilatov A A 2020 *IOP Conf. Series: Materials Science and Engineering* **734** 012184
[36] Likhanov V A and Rossokhin A V 2020 *IOP Conf. Series: Materials Science and Engineering* **734** 012027
[37] Likhanov V A and Lopatin O P 2020 *Journal of Physics: Conf. Series* **1515** 042008
[38] Lopatin O P 2020 *Journal of Physics: Conf. Series* **1515** 052004
[39] Chupashev A N and Chuprakov A I 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 062083
[40] Likhanov V A and Lopatin O P 2020 *Journal of Physics: Conf. Series* **1515** 042019
[41] Skryabin M L and Likhanov V A 2019 *Journal of Physics: Conference Series* **1399** 044063
[42] Likhanov V A and Anfilatov A A 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 032050
[43] Skryabin M L 2020 *Journal of Physics: Conf. Series* **1515** 042107
[44] Likhanov V A and Anfilatov A A 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 032044
[45] Likhanov V A and Lopatin O P 2018 *Ecology and Industry of Russia* **22**(10) 54-9
[46] Likhanov V A and Rossokhin A V 2018 *IOP Conf. Series: Materials Science and Engineering* **457** 012007
[47] Likhanov V A and Skryabin M L 2019 *IOP Conf. Series: Earth and Environmental Science* **315** 032045
[48] Likhanov V A and Rossokhin A V 2019 *Journal of Physics: Conf. Series* **1399** 044038
[49] Likhanov V A and Lopatin O P 2020 *IOP Conf. Series: Materials Science and Engineering* **734** 012202
[50] Likhanov V A, Lopatin O P and Yurlov A S 2020 *IOP Conf. Series: Materials Science and Engineering* **734** 012208
[51] Lopatin O P 2020 *IOP Conf. Series: Materials Science and Engineering* **734** 012199
[52] Kozlov A N, Anfilatov A A and Chuvashev A N 2019 *Journal of Physics: Conf. Series* **1399** 055051
[53] Rossokhin A V and Anfilatov A A 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 062065
[54] Anfilatov A A and Chuvashev A N 2020 *Journal of Physics: Conf. Series* **1515** 042077
[55] Anfilatov A A 2020 *Journal of Physics: Conf. Series* **1515** 042098
[56] Likhanov V A, Lopatin O P and Vylegzhanin P N 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 062074
[57] Chuvashev A N and Chuprakov A I 2020 *Journal of Physics: Conf. Series* **1515** 042094
[58] Likhanov V A, Kopchikov V N and Fominykh A V 2020 *Journal of Physics: Conf. Series* **1515** 042026
[59] Anfilatov A A and Chuvashev A N 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 032052
[60] Likhanov V A, Rossokhin A V and Devetyarov R R 2020 *Journal of Physics: Conf. Series* **1515** 042064
[61] Skryabin M L and Grebnev A V 2020 *Journal of Physics: Conf. Series* **1515** 052052
[62] Likhanov V A and Lopatin O P 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 062027
[63] Skryabin M L 2020 *Journal of Physics: Conf. Series* **1515** 042833
[64] Likhanov V A and Lopatin O P 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 062033
[65] Likhanov V A, Lopatin O P and Vylegzhanin P N 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 062078
[66] Lopatin O P 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 062025
[67] Anfilatov A A and Chuvashev A N 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 032055
[68] Devetyarov R R 2020 *IOP Conf. Series: Materials Science and Engineering* **862** 062072
[69] Somasundaram S, Mohanraj T, Raju S P and Mohankumar K M 2017 *Lecture Notes in Mechanical Engineering* 9 507-16