Influence of crankshaft speed on 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

Abstract. At present, the use of renewable alternative fuels of non-petroleum origin has become a challenge. Primarily, this is due to the fact that oil resources are gradually being depleted, and their cost is growing proportionally every year. Switching to renewable fuels will reduce air pollution and ensure independence from crude oil. The article presented describes the results of bench tests of an air-cooled diesel engine 2F 10.5/12.0 running on methyl alcohol and methyl ether of rapeseed oil. Herewith, a dual fuel supply system was used. That allowed ensuring synchronous fuel feeding into the engine cylinder. The article also presents diagrams of indicator pressure, heat release and roughness of the combustion process of a diesel engine running on alternative fuels, depending on the change in the crankshaft speed. Along with this, positive environmental effects were also revealed in terms of the amount of toxic agents in the exhaust gases of a tractor diesel engine. Thus, there is a significant reduction in nitrogen oxides (by 47.4%) as compared to the diesel process, and the soot content in the exhaust gases has decreased by 10.42 times.

Modern diesel internal combustion engines are very high-tech, having an increased service life, reliability, high traction and power performance, as well as economic efficiency. They are widely used in the automotive industry for special-purpose vehicles, freight and passenger transport, and in agriculture. These days, it is difficult to imagine any industrial sector without the use of diesel engines. However, many scientists have been recently searching for alternative fuels [1-24]. This is done in order to obtain energy independence from fossil oil resources, as well as to improve environmental security in the world [25-48]. The combustion of petroleum diesel fuel releases a large number of toxic substances into the air negatively affecting vegetation, animals and nature in general. New alternative fuels must not only meet all safety requirements, but also they have to be similar in their physical and chemical properties to petroleum diesel fuel [49-57]. This is essential because in the future, when using new alternative fuels, it will be possible not to introduce significant design modifications to the internal combustion engine. The proposed fuels must also be renewable [58-73].

These goals can be achieved by using such fuels as methyl alcohol (methanol) and rapeseed oil methyl ether (RME). Both types of fuel are classified as "biodiesel", since methyl alcohol can be obtained from wood processing by-products, food waste and gaseous fuels, while methyl ether is produced from rapeseed oil. Owing to the presence of oxygen in the composition, these fuels emit fewer toxic agents during combustion. However, due to a low cetane number, alcohol is not capable of self-ignition, in contrast to methyl ester. The solution to this problem is to install a dual fuel supply system (DFS) on a diesel engine. This system will allow simultaneous feed of the above-mentioned fuels.
The Department of Heat Engines, Vehicles and Tractors of the Vyatka state agricultural Academy conducted bench tests of a 2F 10.5/12.0 diesel engine. The peculiarity of the tests was that an additional high-pressure fuel pump was installed through a specially made spacer on the engine. Alcohol was supplied to the cylinder through the standard fuel supply system, and for ether feeding, additional holes for injectors were made in the cylinder heads. It is specified that, methyl alcohol and methyl ether were fed simultaneously at fixer angles equal to 34° to the top dead centre (TDC). These adjustments proved to be optimal, since total specific effective fuel consumption was at minimum.

During the tests, the following characteristics were monitored: fuel consumption, air consumption, crankshaft speed, and torque. In addition, an indexing sensor was installed in the head of the first cylinder, and exhaust emissions were measured by means of a gas analyzer.

Special attention was paid to the study of the combustion process of alternative fuels in the cylinder, as well as the effects of diesel operating modes on this process. For this purpose, we obtained indicator diagrams at various speed modes. Mathematical processing of these diagrams made it possible to obtain an empirical dependence of the fuel combustion process in the form of a heat release function, which shows the proportion of heat released by a specific time (integral characteristic of heat release \( \chi \)) or the rate of heat release (differential characteristic of heat release \( \frac{d\chi}{d\varphi} \)).

The indicator diagrams obtained as a result of bench tests are shown in figure 1.

![Figure 1. Comparative indicator diagrams.](image-url)

In this diagram, one can see how the indicator pressure changes depending on changes in the speed mode of the engine. It can be observed that as the speed grows, the maximum gas pressure in the diesel cylinder decreases, the entire combustion process shifting to the expansion line.

From figure 2, we can also observe that increasing crankshaft speed leads to a decline in the maximum escalation rate the "roughness" pressure.

Such decline in the maximum gas pressure in the diesel cylinder and roughness with an increase in crankshaft speed is due to special character of methanol vapors burning up. Figures 3 and 4 show the integral and differential characteristics of heat release as a function of crankshaft rotation angle at various speed modes. The analysis of these diagrams showed that in general, during methanol
combustion with the igniter fuel, the entire combustion process could be divided into two characteristic parts. At the first interval, the combustion process is distinguished by a high rate of heat release, which is due to the high rate of methanol vapors’ burning up, including those, which were formed during the ignition delay period. The second section of the heat release curve has a flatter shape, and is time-extended. This form of heat release curve is primarily due to the diffusion combustion of the igniter PME and the secondary combustion of large drops of methanol that were not burnt during the initial period.

Considering the heat release characteristics (figures 3 and 4), one can see that with increasing of rotation speed in the first interval, there is a decline in heat release rate, and the whole process of heat generation moves to the right towards expansion.
This is because during this period, the kinetic mechanism of methanol vapors’ burning out prevails with the spread of the flame front from the igniter fuel foci. Due to the limited rate of this process at high crankshaft speed of the diesel engine, there is a delay in the fuel combustion process following the increasing volume of the combustion chamber, which is not typical for the diesel process.

Therefore, it can be concluded that the use of methanol and RME as fuel in diesels with DST imposes certain specific features on the combustion process. In particular, the speed characteristic of the test engine shows that when it is running at low speeds, one can observe a high rate of fuel combustion and high gas pressure in the cylinder. With increasing crankshaft speed, due to predominance of the kinetic mechanism of methanol vapors’ burning out, there is a decline in the maximum intensity of heat release and consequently, the maximum indicator pressure decreases.

References
[1] Somasundaram S, Mohanraj T, Raju S P and Mohankumar K M 2017 Lecture Notes in Mechanical Engineering (9) 507-16
[2] Kopchikov V N and Fominykh A V 2020 Journal of Physics: Conf. Series 1515 042028
[3] Likhanov V A and Anfillatov A A 2020 IOP Conf. Series: Materials Science and Engineering 862 032048
[4] Likhanov V A and Rossokhin A V 2019 Journal of Physics: Conf. Series 1399 044038
[5] Devetyarov R R and Chupashev A N 2020 Journal of Physics: Conf. Series 1515 042080
[6] Skrabin M L 2020 Journal of Physics: Conf. Series 1515 042107
[7] Lopatin O P 2020 Journal of Physics: Conf. Series 1515 042021
[8] Likhanov V A, Lopatin O P and Yurlov A S 2020 IOP Conf. Series: Materials Science and Engineering 734 012208
[9] Chupashev A N and Chuprakov A I 2020 IOP Conf. Series: Materials Science and Engineering 862 062089
[10] Likhanov V A, Kopchikov V N and Fominykh A V 2020 Journal of Physics: Conf. Series 1515 042026
[11] Lopatin O P 2020 IOP Conf. Series: Materials Science and Engineering 862 062087
[12] Likhanov V A and Rossokhin A V 2018 IOP Conf. Series: Materials Science and Engineering
862 032044

[48] Likhanov V A and Lopatin O P 2020 Journal of Physics: Conf. Series 1515 052002
[49] Likhanov V A and Lopatin O P 2018 Ecology and Industry of Russia 22(10) 54-9
[50] Anfilatov A A and Chuvash A N 2020 Journal of Physics: Conf. Series 1515 022035
[51] Kozlov A N, Anfilatov A A and Chuvash A N 2019 Journal of Physics: Conf. Series 1399 055051
[52] Anfilatov A A and Chuvash A N 2020 Journal of Physics: Conf. Series 1515 042077
[53] Likhanov V A and Lopatin O P 2020 IOP Conf. Series: Earth and Environmental Science 421 072018
[54] Likhanov V A, Lopatin O P and Vylegzhanin P N 2020 IOP Conf. Series: Materials Science and Engineering 862 062074
[55] Lopatin O P 2020 Journal of Physics: Conf. Series 1515 052004
[56] Romanyuk V, Likhanov V A and Lopatin O P 2018 Theoretical and Applied Ecology 3 27-32
[57] Uludamar E 2018 International Journal of Hydrogen Energy 43 (38) 18028-36
[58] Likhanov V A and Lopatin O P 2019 Journal of Physics: Conf. Series 1399 055016
[59] Anfilatov A A and Chuvash A N 2020 IOP Conf. Series: Materials Science and Engineering 862 032052
[60] Skryabin M L and Likhanov V A 2020 IOP Conf. Series: Materials Science and Engineering 734 012075
[61] Chuvash A N and Chuprakov A I 2020 IOP Conf. Series: Materials Science and Engineering 862 062083
[62] Likhanov V A, Rossokhin A V and Devetyarov R R 2020 Journal of Physics: Conf. Series 1515 042064
[63] Likhanov V A, Kozlov A N and Araslanov M I 2020 IOP Conf. Series: Materials Science and Engineering 734 012211
[64] Skryabin M L and Grebnev A V 2020 Journal of Physics: Conf. Series 1515 052052
[65] Likhanov V A, Lopatin O P and Vylegzhanin P N 2020 IOP Conf. Series: Materials Science and Engineering 862 062078
[66] Likhanov V A and Lopatin O P 2018 IOP Conf. Series: Materials Science and Engineering 457 012011
[67] Lopatin O P 2020 IOP Conf. Series: Materials Science and Engineering 862 062025
[68] Chuvash A N and Chuprakov A I 2019 Journal of Physics: Conf. Series 1399 055085
[69] Luning Prak D J, Ye S, McLaughlin M, Trulove P C and Cowart J S 2018 Industrial and Engineering Chemistry Research 57(2) 600-10
[70] Anfilatov A A and Chuvash A N 2020 Journal of Physics: Conf. Series 1515 042052
[71] Li X, Zheng Y, Guan C, Huang Z and Cheung C S 2018 Environmental Science and Pollution Research 25 (34) 34131-8
[72] Shatrov M G, Sinyavski V V, Dunin A Yu, Shishlov I G and Vakulenko A V 2017 Facta Universitatis. Series: Mechanical Engineering 15(3) 383-95
[73] Arul Gnana Dhas A, Nagappan B and Devarajan Y 2018 International Journal of Green Energy 15 (7) 436-40