Investigation of the portion size of rapeseed oil for ethanol ignition in a diesel engine

V A Likhanov, A N Kozlov and M I Araslanov

Department of thermal engines, automobiles and tractors, Vyatka State Agricultural Academy, 610017, Kirov, October prospect, 133, Russian Federation

E-mail: dnka59@mail.ru

Abstract. Currently, the search for alternative renewable fuels for internal combustion engines is becoming strategic. At the same time, it is necessary to work on adapting and improving the design of power transport units, conduct research on optimizing the composition of fuels, their quality and safety, and improve the combustion process of fuels in the cylinder. Vegetable oil-based fuels and alcohol-based fuels are well established and widely distributed. Their valuable property is that when burned, they are less prone to the formation of toxic components and carcinogens. The purpose of this work was to analyze the characteristics of the diesel engine and the combustion process when working on ethanol and rapeseed oil when changing the ratio of cyclic feeds. At the same time, diesel fuel was not used and alcohol fuel was injected into the combustion chamber by a separate injector and ignited with a flame from the rapeseed oil. A 2F10,5/12,0 tractor diesel was upgraded to run on alternative fuels. The article presents the effective characteristics, indicator diagrams, the functions of heat dissipation and the average gas temperature at various portions of the rapeseed oil. The optimal relations portions of the fuels (ethanol and rapeseed oil) is established and justified.

1. Introduction

Internal combustion engines are currently one of the main sources of mechanical energy. In terms of their combined properties, they meet the requirements for them, and in the near future, they are not expected to be replaced by other, fundamentally different mechanical energy sources. However, the steady growth in the number of internal combustion engines has led to the fact that at the moment, auto-tractor diesels are one of the main sources of toxic emissions into the atmosphere. Thus, improving the economic and environmental indicators is a priority of the improvement and development of piston internal combustion engines. One of the ways to improve the performance of internal combustion engines is the use of alternative fuels, including fuels from renewable raw materials of biological origin. Biofuels from renewable raw materials of plant or animal origin can partially or completely eliminate petroleum fuels, as well as significantly improve the environmental performance of the internal combustion engine. The use of biofuels is impossible without a deep and consistent analysis of the combustion process in a diesel engine at various load and speed modes, necessary for the accumulation and refinement of knowledge about the combustion process and heat generation in the cylinder. These studies are also important for determining the optimal adjustments of fuel supply equipment, designing the combustion chamber of modern diesel, and forming requirements for the physical and chemical properties of the fuel [1-8].
Researchers from all over the world offer various methods of using vegetable oils in internal combustion engines. These methods include pyrolysis, micro emulsification, direct mixing with diesel fuel, transesterification, etc. In many works, there is an improvement in the environmental performance of the engine. The use of vegetable oils in their pure form is difficult for a number of reasons. The most adapted among them for serial diesel engine is rapeseed oil (RO). It has a sufficiently high cetane number and is able to ignite independently in the conditions of the diesel combustion chamber, therefore, it can be used as a ignition fuel. The main disadvantage of RO is its high viscosity, which leads to a worsening of the mixture formation and an increase in the duration of fuel combustion [9-14]. This in turn worsens the effective performance of the diesel engine. To reduce the duration of fuel combustion and improve the efficiency and environmental performance of diesel, a light alcohol fuel with a low cetane number can be used. Ignition of alcohol is provided by a portion of the ignition fuel (RO) injected into the combustion chamber by a separate injector [15-19].

2. Materials and methods
In the Vyatka State Agricultural Academy, the Department of Heat Engines, Automobiles and Tractors conducted research on the work of a tractor diesel engine under various operating conditions. Part of the presented research was bench testing of a tractor diesel 2F 10.5/12.0 with a hemispherical combustion chamber in the piston, modified to run on ethanol and RO [20-24]. The main characteristics of the diesel engine are shown in table 1.

| Table 1. Main diesel engine characteristics and operating mode parameters. |
|---------------------------------------------------------------|
| **Diesel** | **2F 10.5/12.0** |
| Diesel type | Air cooling with the hemispherical combustion chamber |
| Number of cylinders | 2 |
| Working volume | 2080 cm³ |
| Nominal frequency of crankshaft rotation | 1800 rpm |
| Piston diameter | 105 mm |
| Piston stroke | 120 mm |
| Compression ratio | 16.5 |
| The installation angle of the injection of fuel | 30 deg. bTDC |
| Rated power | 18.4 kW |
| Mean effective pressure | 0.588 MPa |
| Specific effective fuel consumption | 241.8 g/kW·h |

Starting the diesel engine and changing the load was performed by an electric brake balancing machine. During the tests, all the necessary parameters were measured: fuel consumption, mass air flow, diesel load. The mass air flow was measured using the gas flow meter installed in front of the diesel intake manifold, and the electronic digital tachometer. The fuel consumption was measured using the electronic fuel flow meter. At the same time, the exhaust gas composition and soot content were monitored by the gas analysis system. The diagram of the laboratory setup is shown in figure 1.

The diesel workflow was investigated by a piezo-quartz pressure sensor PS-01, after which the signal from the sensor was sent to the amplifier, the amplified signal was sent to a personal computer via an analog-to-digital converter [25-28].

The calculation of the indicator temperature of gases in the cylinder and the rate of heat release, the rate of heat removal was carried out using the method of the Central research diesel Institute (Moscow). The initial data for the calculation is the energy characteristic of fuels, fuels (ethanol and RO) consumption and excess air coefficient [29-32].
Figure 1. Scheme of laboratory installation: 1- diesel 2F10.5/12.0; 2- weight mechanism Rapido; 3- electric balancing machine SAK-N-670; 4- personal computer; 5 LA-2 analog-to-digital converter; 6- electronic fuel flow meter AIR-50; 7- fuel tank; 8- Gas analysis system ASGA-T; 9- smoke meter; 10- speed sensor KV; 11 TDC sensor; 12- cylinder pressure sensor PS-01; 13- fuel pressure sensor TDT; 14- high pressure fuel pump; 15- RG-250 air flow meter; 16- exhaust gases temperature sensor; 17- receiver.

3. Results
As a result of the experiment, it was found that the minimum supply of ignition fuel $q_{RO}$, at which the engine worked without ignition passes, can be set to 8.3 mg/cycle ($G_{RO} = 0.9$ kg/h) at the rated speed of the engine crankshaft $n = 1800$ rpm and 6.1 mg/cycle ($G_{RO} = 0.51$ kg/h) at $n = 1400$ rpm. With an increase in the portion of the RO, the cyclic supply of ethanol decreases accordingly. Thus, with a minimum supply of RO fuel, the ethanol consumption in the nominal operating mode engine was $G_{et} = 7.3$ kg/h ($q_{et} = 68$ mg/cycle). When the RO supply was increased to $G_{RO} = 2.1$ kg/h ($q_{RO} = 19.4$ mg/cycle), the ethanol consumption was $G_{et} = 5.2$ kg/h ($q_{et} = 46$ mg/cycle) (table 2). When evaluating the energy efficiency of a diesel engine, it is advisable to use an equivalent calorific consumption of ethanol and RO, which is reduced to the calorific value of diesel fuel. The following values of calorific value were used in the calculations: for RO = 8909 kcal/kg, for ethanol = 6405 kcal/kg, for diesel fuel = 10150 kcal/kg. Then the value of the reduced fuel consumption at the minimum supply of RO at the nominal speed and mean effective pressure $p_e = 0.588$ MPa will be equal $G_{eq} = 5.4$ kg/h (figure 2).

Table 2. Volume of fuel injection at the nominal operating mode of the diesel engine.

| Fuel      | Injection volume mg/cycle |
|-----------|---------------------------|
| RO ($q_{RO}$) | 8.3    | 11.7 | 15.4 | 19.4 |
| Ethanol ($q_{et}$) | 68     | 54   | 51   | 46   |
The minimum fuel consumption equivalent in terms of heat of combustion at the nominal mode of operation of the diesel engine is in the range of RO supply $G_{RO} = 1.3...1.5 \text{ kg/h}$, is $G_{eq} = 4.6 \text{ kg/h}$, when working with the speed of the crankshaft $n = 1400 \text{ rpm}$ respectively $G_{RO} = 0.9...1.2 \text{ kg/h}$ and $G_{eq} = 3.3 \text{ kg/h}$.

![Figure 2](image)

**Figure 2.** Effect of the value of the cycle portion on the equivalent fuel consumption at $n=1800 \text{ rpm}$.

The best values of the effective characteristics of the engine are achieved with a cyclic supply of RO in the range from 11 to 14 mg/cycle. At the nominal operating mode, when the portion of RO is fed 11.7 mg/cycle, the total fuel consumption $G_\Sigma = 7.06 \text{ kg/h}$, ethanol consumption, $G_\alpha = 5.81 \text{ kg/h}$, the total specific effective fuel consumption $g_{e\Sigma} = 384.5 \text{ g/(kW·h)}$, the specific effective efficiency $\eta_e = 0.324$.

In the maximum torque mode, the maximum effective efficiency of $\eta_e = 0.334$ was achieved at $q_{RO} = 12.5 \text{ mg/cycle}$. In this case, the total fuel consumption was $G_\Sigma = 4.92 \text{ kg/h}$, and ethanol consumption $G_\alpha = 3.87 \text{ kg/h}$. A further increase in the cycle supply of RO leads to a decrease in the overall fuel consumption. Thus, with a cyclic supply of RO $q_{RO} = 15.5 \text{ mg/cycle}$, the ethanol consumption is equal to $G_\alpha = 3.54 \text{ kg/h}$, respectively, the total consumption of $G_\Sigma = 4.84 \text{ kg/h}$. However, the specific effective fuel consumption $g_{e\Sigma} = 235 \text{ g/(kW·h)}$, which is higher than for the ignition portion $q_{RO} = 12.5 \text{ mg/cycle}$ per 2 g/(kW·h). The effective efficiency decreases slightly and is $\eta_e = 0.32$.

In the same range of values of the ignition portion RO are the extremes of the functions of air flow $G_\alpha$, excess air coefficient $\alpha$, filling coefficient $\eta_V$, exhaust gas temperature $t_e$. The maximum value of the excess air coefficient was obtained $\alpha = 1.72$ at $q_{RO} = 11.7 \text{ mg/cycle}$ at $n = 1800 \text{ rpm}$ and $\alpha = 1.89$ at $q_{RO} = 12.5 \text{ mg/cycle}$ at the speed of rotation of the crankshaft $n = 1400 \text{ rpm}$.

The effect of the PM portion value on the effective performance of the diesel engine is shown in figure 3. The assessment of the effect of the RO portion value on the effective performance is the first stage of research, the next stage was to evaluate the effect of the portion value on the combustion process and the characteristics of heat release in the diesel cylinder [33-38].

Indicators of the combustion process and heat release characteristics were obtained as a result of processing experimental indicator diagrams recorded during bench tests. Indicator diagrams - curves of pressure changes in the cylinder during the working cycle are used as one of the tools for describing and analyzing the quality of the engine’s working cycle. Graphs of the effect of the value of the portion value of the RO on the parameters of the combustion process and the characteristics of heat release are shown in figure 4.
With increasing the cyclic feed of RO there is an increase in the maximum combustion pressure. At the same time, there is an increase in the rate of pressure build-up in the diesel cylinder. The rate of pressure increase in the engine cylinder determines the level of acoustic noise produced by the engine, which in turn is one of the environmental indicators of the internal combustion engine [39-43].

With an increase in the ethanol portion, the efficiency of alcohol atomization improves, but at the same time, the fuel supply time increases, the evaporation process slows down, there are more re-enriched zones in the ethanol fuel flare, and the local coefficient of excess air in the thermal decomposition zone decreases. However, it is necessary to take into account the change in the geometric parameters of the fuel flare. With a decrease in the supply of the ignition RO, the uneven flow through the cylinders increases and the fuel injection pressure decreases, which leads to a deterioration in the quality of fuel atomization in the combustion chamber. There is an increase in the average diameter of drops and, accordingly, the duration of their evaporation. As a result, the ignition delay period increases, the combustion process shifts to the expansion line, and the exhaust temperature increases. All this leads to an increase in the total fuel consumption and a decrease in the excess air coefficient, which additionally leads to a decrease in the burn rate of soot particles, increased exhaust smoke. Due to the late initiation of the combustion process, not only the effective efficiency decreases, but also the heat release significantly decreases, which indicates incomplete combustion of the fuel [44-48].

Gradually increasing the cycle flow of RO, we improve the characteristics of fuel atomization, reducing the uneven flow through the cylinders, which is reflected in the reduction of the ignition delay period of the fuel-air mixture. Increases the completeness of fuel combustion increases the effective efficiency. At the same time, the temperature of the gases in the cylinder increases, the degree of homogenization of the mixture decreases during the initial combustion period, and the mass of the fuel
that is burned in the diffusion mode increases. With cyclic portions of RO over 16 mg/cycle, the range of the fuel torch increases, part of which can be deposited on the walls of the combustion chamber, which also worsens the process of mixing and leads to a decrease in the total heat release and as a result leads to an increased total fuel consumption. In addition, excessive range of the fuel flare can lead to the transfer of part of the unburned fuel into the diesel crankcase and mixing it with engine oil.

Figure 4. Indicators of the combustion process and heat release characteristics depending on the value portion of RO and degrees of rotation of the crankshaft (deg. of c.r.) on the: a – cylinder pressure; b - gas temperature in the cylinder; c – heat release; d – heat release rate

4. Conclusions
The optimal value of the ignition fuel supply is set at 13 mg/cycle. With an increase in the supply of ignition fuel, the environmental performance of the diesel engine deteriorates, and the content of unburned hydrocarbons in the exhaust gases gradually increases. With a decrease portion value of RO - the period of delay in ignition of the fuel-air mixture increases excessively, the combustion process shifts to the expansion line, and the effective efficiency decreases.

Similar conclusions can be drawn when analyzing the operation of a diesel engine in other modes of operation on ethanol and rapeseed oil. The value of the optimal ignition fuel supply may change slightly when changing the operating mode or change setting the fuel injection advance angle.

References
[1] Asad U and Zheng M Fast heat release characterization of a diesel engine 2008 International
Journal of Thermal Sciences 47 1688-700

[2] Kozlov A N, Anfilatov A A and Chuvashev A N 2019 Journal of Physics: Conf. Series 1399 055051

[3] Likhanov V A and Rossokhin A V 2018 IOP Conference Series: Materials Science and Engineering 457 doi: 10.1088/1755-1315/457/1/012007

[4] Sahin Z, Kurt M and Durgun O 2018 Heat release analysis of gasoline fumigation in a diesel engine Energy Procedia 147 322-8

[5] Likhanov V A, Lopatin O P and Yurlov A S 2020 IOP Conf. Series: Materials Science and Engineering 734 012208

[6] Srinidhi C, Madhusudhan A and Durgun O 2018 Heat release analysis of gasoline fumigation in a diesel engine Energy Procedia 147 322-8

[7] Zhang R, Pham P X, Kook S and Masri A R 2019 Influence of biodiesel carbon chain length on in-cylinder soot processes in a small bore optical diesel engine Fuel 235 1184-94

[8] Likhanov V A and Lopatin O P 2018 IOP Conf. Series: Materials Science and Engineering 457 012011

[9] Zhang S, Zhao C and Zhao Z 2014 Heat Release Analysis of Hydraulic Free Piston Diesel Engine Energy Procedia 61 2505-8

[10] Likhanov V A and Lopatin O P 2018 Ecology and Industry of Russia 22(10) 54-9

[11] Likhanov V A and Skryabin M L 2019 IOP Conference Series: Earth and Environmental Science 315 doi:10.1088/1755-1315/315/3/032045

[12] Likhanov V A, Chuprakov A I and Anfilatov A A 2020 IOP Conf. Series: Materials Science and Engineering 734 012184

[13] Likhanov V A and Lopatin O P 2020 IOP Conf. Series: Materials Science and Engineering 734 012202

[14] Chuprakov A I and Anfilatov A A 2019 Journal of Physics: Conf. Series 1399 055085

[15] Lopatin O P 2020 IOP Conf. Series: Materials Science and Engineering 734 012199

[16] Skryabin M L 2020 IOP Conf. Series: Earth and Environmental Science 421 072012

[17] Yuson Y 2019 Energy 186 115768

[18] Likhanov V A and Lopatin O P 2019 Journal of Physics: Conf. Series 1399 055020

[19] Guedes A D M, Braga S L and Pradelle F 2018 Fuel 225 174-83

[20] Romanivuk V, Likhanov V A and Lopatin O P 2018 Theoretical and Applied Ecology 3 27-32

[21] Smith, O. J. Fundamentals of Soot Formation in Flames with Application of Diesel Engine particulate Emissions 1981 Progress in Energy and Combustion Science 7 275-91

[22] Hemmerlein N, Korte V and Richter H Performance exhaust emissions and durability of modern diesel engines running on rapeseed oil SAE 1991 Technical Paper Series 910848

[23] Likhanov V A and Lopatin O P 2019 Journal of Physics: Conf. Series 1399 055016

[24] Kittelson D and Kraft M Particle formation and models in internal combustion engines 2014 Cambridge centre for computational chemical engineering 39

[25] Klippenstein S, Georgievskii Y and Harding L Predictive theory for the combination kinetics of two alkyl radicals 2006 Phys. Chem. Chem. Phys. 8 1133-47

[26] Lopatin O P 2020 IOP Conf. Series: Earth and Environmental Science 421 072019

[27] Wagner, H. Gg Soot formation in combustion 1979 17th Int. Symp. Combust. 3-19

[28] Vyrubov D N, Ivashchenko N A, Ivin V I, et al. 1983 Internal combustion engine: Theory of piston and combined engines (Moscow:Mechanical engineering) 372 p

[29] Likhanov V A and Lopatin O P 2020 IOP Conf. Series: Earth and Environmental Science 421 072018

[30] Voinov A N 1977 Combustion in high-speed piston engines (Moscow:Mechanical engineering) 277 p

[31] Khan I M Formation and combustion of carbon in a diesel engine 1969 Inst. Mech. Eng. Proc. 184 36-43
[32] Dincer I and Zamfirescu C 2016 Journal of Natural Gas Science and Engineering 28 461-78
[33] Likhanov V A, Lopatin O P and Yurlov A S 2019 Journal of Physics: Conf. Series 1399 055026
[34] Datta A and Mandal B K 2016 Applied Thermal Engineering 98 670-82
[35] Arent D J, Wise A and Gelman R 2011 Energy Economics 33 584-93
[36] Chang W R, Hwang J J and Wu W 2017 Renewable and Sustainable Energy Reviews 67 277-88
[37] Likhanov V A and Lopatin O P 2017 Thermal Engineering 64(12) 935-44
[38] Aydin F and Ogut H 2017 Renewable Energy 103 688-94
[39] Lif A and Holmberg K 2006 Advances in Colloid and Interface Science 123 231-39
[40] Yadava S and Maitra S S 2017 Global Nest Journal 19 533-39
[41] Likhanov V A and Lopatin O P 2019 Ecology and Industry of Russia 23(9) 60-5
[42] Ahmad I 2016 Journal of Pure and Applied Microbiology 10 95-102
[43] Chen W, Pan J, Liu Y, Fan B, Liu H and Otchere P 2019 Applied Energy 176 453-467
[44] Semprini S, Sánchez D and De Pascale A 2016 Solar Energy 132 279-93
[45] Marchuk A, Likhanov V A and Lopatin O P 2019 Theoretical and Applied Ecology 3 080-6
[46] Presser C, Nazarian A and Millo A 2018 Fuel 214 656-66
[47] Frances C 2009 Sustainability 1 43-54
[48] Rajesh Kumar B and Saravanan S 2016 Renewable and Sustainable Energy Reviews 60 84-115