Rapeseed Oil is the Base for Biodiesel Fuel

M V Zapevalov 1, N S Sergeev 1, G V Redreev 2, a

1 South Ural State Agrarian University, Chelyabinsk
2 Omsk State Agrarian University named after P.A. Stolypin, 644008, Omsk, Institutskaya pl. St., 1

E-mail: a weerwg@mail.ru

Abstract. Many countries all over the world including the Russian Federation are carrying out the research devoted to the replacement of mineral fuel to environmentally friendly fuel. One of these types can be biodiesel fuel based on vegetable oils. Any oil can be used for this purpose; however, rapeseed oil fuel seems to be the most rational one. Even in ancient times it was used in lanterns to light the streets, to lubricate metal parts that were in contact with water and steam to prevent them from corrosion. It is currently used in hydraulic systems of tractors and agricultural machines. The aim of the study is to determine the comparative operational parameters of a diesel engine when running on diesel fuel and fuel based on rapeseed oil. Rapeseed oil differs significantly from diesel fuel in viscosity and flash temperature; if diesel viscosity is 4.3 mm²/s, rapeseed oil viscosity is 75.1 mm²/s. The mixture consisting of 75% rapeseed oil and 25% diesel fuel has a viscosity of 36.0 mm²/s, and the density and lower combustion heat are close to diesel fuel parameters. The studies on preparing the rapeseed oil and diesel fuel mixture have been carried out in the South Ural State Agrarian University; they resulted in developing a production line for making the fuel mixture and conducting the comparative tests of the D-240 engine when working on diesel mineral fuel and when working on fuel consisting of a mixture of 75% rapeseed oil and 25% diesel fuel. It has been found that at a nominal frequency of engine crankshaft rotation (2170 rpm) the efficient power of the engine running both on diesel fuel and on a mixture of rapeseed oil and diesel fuel is 53.3 kW. With the same torque of 235 N/m the efficient fuel mixture consumption is only 17 g/kWh more. This gives the reasons for using this mixture as a fuel in a diesel engine in terms of energy parameters.

Introduction

Rapeseed as an agricultural crop has been known to mankind for more than two thousand years. Rapeseed is used for both food and technical needs. The cultivated area of rapeseed in the world is constantly growing. It is cultivated in 50 countries on the areas of over 26 million hectares. Rapeseed cultivation is common in the countries with temperate climate; it is more popular in India, Canada, China, Germany, France, Great Britain, Poland. The largest rapeseed areas are in India and Canada. In the countries of the European Union the leading place of rapeseed growing belongs to Germany and France.

The demand for vegetable oils is growing in many countries all over the world including the Russian Federation. In this regard the cultivated area of oil crops is increasing, and the technology of their cultivation is being improved. In the Chelyabinsk region, in the sphere of oil crops growing, the spring rapeseed area varies from 30 to 50 thousand ha over the years. Due to its faulty cultivation technology, the average seed yield does not exceed 11 kg/ha, although the climatic conditions of the Southern Urals enable to obtain the yields up to 20 kg/ha. The area of oil crops including rapeseed amounted to 205.5 thousand hectares in the Chelyabinsk region in 2019 [3].

Agricultural production is associated with high energy costs. This primarily relates to fuel and lubricants. In Russia, in the sphere of crop cultivation technology, the average fuel consumption per hectare is about 50 kg of diesel fuel. It should be noted, that the share of fuel cost in the cost price of cultivated agricultural products exceeds 20%. Thus, the increasing fuel prices lead to the growth in the
cost of agricultural products, while the price containment in the market leads to a decrease in the profitability of the economy [1].

Russia is one of the main suppliers of natural energy resources to the world market. The stock of these resources is not unlimited; therefore, the studies related to the use of alternative energy sources are being carried out worldwide. At present there is an important issue of replacing mineral fuel with another one that will be environmentally friendly. One of these types, in particular for agriculture, can be biodiesel fuel based on vegetable oils [2].

Extensive research focused on the use of vegetable oil as a fuel for diesel engines was carried out in the 70s of the last century. It is known that a molecule of fat consists of trivalent glycerol alcohol combined with three fatty acid molecules. If one unit of methanol is added to nine mass units of vegetable oil, then under certain conditions (as a result of a chemical reaction), methyl ester and glycerin are formed. Methyl ester is a biofuel. There are some other ways to prepare it, for example by neutralizing glycerol [4].

Biofuels can be obtained from any vegetable oil, but rapeseed oil is the most rational one. Rapeseed is an annual oil plant from the cruciferous family. Depending on the variety and cultivation conditions, the seeds contain from 30 to 50% of oil. Rapeseed oil contains the following acids: oleic (43.7%); linoleic (20.9%); erucic (15.4%); linolenic (8.5%); palmitic (4.8%); eicosene (4.8%); stearic (1.7%). Rapeseed oil is a valuable dietary product, since it contains a rather high amount of polyunsaturated fatty acids; however, it is widely used for technical needs. In ancient times, rapeseed oil was used in lanterns to lighten the streets, to lubricate metal parts which were in contact with water and steam in order to prevent corrosion. It is currently used in hydraulic systems of tractors and agricultural machines. It is also an excellent raw material for the production of biodegradable plastics and environmental fuels for heat engines. If mineral oil gets in the soil, then the plants die and cannot germinate in this place for several years. Rapeseed oil does not have a benzene smell, and if it penetrates into the soil or water, it does no harm to plants or living organisms. It has a short decay period (28-30 days). It almost does not contain sulfur, while about 0.5% is emitted during the combustion of mineral diesel fuel. During combustion, as much carbon dioxide is emitted as it was consumed by the plant from the atmosphere to produce oil for the entire period of its life. It has good lubricating properties, which help to increase the life of the fuel pump and the engine itself [5]. The increased ignition temperature of rapeseed oil ensures its fire safety. All this indicates the rationality of using rapeseed oil as diesel engine fuel, which can be prepared in an agricultural enterprise with a cost price below the purchase price of mineral diesel fuel.

**Objective:** To determine the comparative operational parameters of a diesel engine when operating on diesel fuel and the fuel based on rapeseed oil.

**Research tasks:**
1. To substantiate the technical practicability of using rapeseed oil as a diesel engine fuel.
2. To develop the scheme of the production line for preparing the fuel mixture. To prepare a fuel mixture of rapeseed oil with diesel fuel.
3. To conduct some comparative tests of a diesel engine when running on diesel fuel and a mixture of rapeseed oil with diesel fuel.

**Materials and methods**

Despite the differences in the physical-chemical properties of rapeseed oil and diesel fuel (Table 1), rapeseed oil is currently being used more and more as a main component in producing biodiesel fuels [6]. These two components mix well, and the resulting mixture has properties that help it to be burned in a diesel engine without changing its composition. Rapeseed oil significantly differs from diesel fuel in viscosity and flash temperature; if diesel viscosity is 4.3 mm²/s, rapeseed oil viscosity is 75.1 mm²/s. A mixture of 75% rapeseed oil and 25% diesel fuel has a viscosity of 36.0 mm²/s, a density of 891 kg/m³ and a lower combustion heat of 38.375 MJ/kg, i.e. similar in value to diesel fuel.

**Research results**

The studies related to preparing the mixture of rapeseed oil with diesel fuel and the comparative tests of the D-240 engine when working on diesel mineral fuel and fuel from a mixture consisting of 75% rapeseed oil and 25% diesel fuel have been carried out in the South Ural State Agrarian University.
When producing the mixture, it is necessary to ensure accurate dosing of the components and their uniform mixing. The analysis of existing technologies for metering liquids shows that volume dosing is the most common one. Various methods and technical means are used to provide it; they differ in the functionality and complexity of the structures used. When developing the technological process for producing the fuel mixture, we defined the task to ensure its reliability and simplicity of the structures while following the specified metering accuracy and uniformity of mixing. In this regard, a production line for producing fuel mixture has been developed (Figure 1).

Table 1 - Physical-chemical properties of rapeseed oil and diesel fuel

| No. | Parameters                              | Rapeseed oil  | Diesel fuel |
|-----|----------------------------------------|---------------|-------------|
| 1   | Content, % C; H; O                      | 78.0; 11.5; 10.5 | 85.2; 13.7; 1.1 |
| 2   | Density at 15°C, kg/m³                  | 917           | 800...845   |
| 3   | Kinematic viscosity at 40°C, mm²/s      | 42.1          | 1.5...4.0   |
| 4   | Dynamic viscosity at 20°C, Pa/s         | 68.7×10⁻³     | 3.15×10⁻³   |
| 5   | Surface tension, n/m                    | 33.2×10⁻³     | 27.1×10⁻³   |
| 6   | Lower combustion heat, mJ/m³            | 36,992        | 42,437      |
| 7   | Cetane number                           | 36...55       | 46...49     |
| 8   | Flash temperature, not lower, °C        | 100           | 55          |
| 9   | Solidification temperature, °C          | -23           | -10; -35; -45; -55 |
| 10  | Sulphur content, %                      | 0.005         | 0.5         |
| 11  | Coking characteristics of 10%-th residue, not more than, % | 0.4 | 0.3 |

Figure 1. Scheme of production line for fuel mixture preparation

The production line consists of a container for storing rapeseed oil (1), a container for storing mineral components (2), centrifugal pumps (3), containers for constant oil and mineral components level (4), fluid supply pipelines (5), return pipelines (6), solenoid valves (7), slotted fluid dispensers (8), centrifugal-rotary mixer (9), remote control (10).

The system operates as follows: oil and mineral components are fed by centrifugal pumps 3 from containers 1 and 2 through pipelines 5 to containers for constant oil and mineral components level.
4. When filling containers with liquid to a specified level, excess liquid flows into its containers through a return pipe by gravity force. When the fluid mixer 9 is turned on, the solenoid valves 7 are opened and the fluids enter the slotted fluid dispensers 8 dosing in a certain proportion. Then the liquids are supplied to the mixing device 9. The finished fuel mixture is piped to the storage container.

To ensure high-quality mixing of liquids, a mechanism (a centrifugal-rotary mixer) for mixing liquids of different viscosities has been developed and patented [7]. The design of the production line is easy to maintain and reliable in operation.

Comparative tests of the D-240 engine were carried out in a specialized laboratory of the South Ural State Agrarian University when working with the regulator on the electric run-in-brake stand (KI-5543-GOSNITI). The test results are given in Tables 2 and 3.

Table 2. Test results of the D-240 diesel engine when working with the regulator on diesel fuel

| No. | Parameter name and dimension | Designation | Experiment number |
|-----|-----------------------------|-------------|-------------------|
|     |                             | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1   | Engine shaft rotation frequency, rpm | n | 2350 | 2300 | 2270 | 2200 | 2170 | 2000 | 1650 |
| 2   | The load on the brake, kg    | Pt | 0 | 17.0 | 29.0 | 33.0 | 33.5 | 35.0 | 39.0 |
| 3   | Fuel consumption per experience, g | ΔGt | 50 | 100 | 100 | 100 | 100 | 100 | 100 |
| 4   | Experience duration, s       | T  | 43 | 41 | 30 | 25.5 | 26.5 | 30.5 | 31.8 |
| 5   | Indications of a U-shaped manometer, mm | Δh | 162 | 160 | 158 | 150 | 141 | 133 | 91 |
| 6   | Oil pressure, MPa            | Pm | 2.4 | 2.4 | 2.4 | 2.3 | 2.3 | 2.2 | 2.2 |
| 7   | Oil temperature, C°          | tm | 76 | 82 | 85 | 89 | 90 | 94 | 95 |
| 8   | Coolant temperature, C°      | tl | 72 | 74 | 78 | 80 | 82 | 82 | 83 |
| 9   | Exhaust temperature, C°      | tg | 172 | 285 | 435 | 450 | 555 | 560 | 560 |
| 10  | Atmospheric pressure, kPa     | Benv | 96 | 96 | 96 | 96 | 96 | 96 |
| 11  | Environment temperature, C°  | Tenv | 21 | 22 | 22 | 22 | 22 | 23 | 23 |
| 12  | Hourly fuel consumption, kg/h | Gt  | 4.2 | 8.8 | 12.0 | 14.1 | 13.6 | 11.8 | 11.3 |
| 13  | Cycle fuel supply, mg/cycle   | gt | 14.8 | 31.8 | 44.1 | 53.5 | 52.2 | 49.2 | 57.2 |
| 14  | Air density, kg/m³           | denv | 1.1363 | 1.1325 | 1.1325 | 1.1325 | 1.1325 | 1.1286 | 1.1286 |
| 15  | Actual air consumption, kg/h | GA | 326 | 324 | 322 | 313 | 304 | 295 | 244 |
| 16  | Theoretical air consumption, kg/h | GAT | 381 | 373 | 368 | 356 | 352 | 324 | 267 |
| 17  | Filling ratio                | nV | 0.86 | 0.87 | 0.87 | 0.88 | 0.86 | 0.91 | 0.91 |
| 18  | Excess air ratio             | a  | 5.44 | 2.58 | 1.87 | 1.55 | 1.56 | 1.75 | 1.51 |
| 19  | Conditional average pressure of mechanical losses, MPa | Ppm | 0.23 | 0.22 | 0.22 | 0.22 | 0.21 | 0.20 | 0.17 |
| 20  | Conditional power of mechanical losses, kW | Nw | 21.2 | 20.4 | 19.9 | 18.8 | 18.4 | 15.8 | 11.2 |
| 21  | Torque, N/m                  | Mm | 0 | 119 | 203 | 231 | 235 | 249 | 273 |
| 22  | Average efficient pressure, MPa | Pe | 0 | 0.31 | 0.54 | 0.61 | 0.62 | 0.66 | 0.72 |
| 23  | Efficient, kW                | Ne | 0.0 | 28.7 | 48.3 | 53.2 | 53.3 | 52.0 | 47.2 |
| 24  | Specific efficient fuel consumption, g/kW h | gth | 306 | 249 | 265 | 255 | 227 | 240 |
| 25  | The unit cost of fuel, RUB./kWh | eH | 10.19 | 8.29 | 8.82 | 8.49 | 7.56 | 7.99 |
| 26  | Average indicator pressure, MPa | Pi | 0.23 | 0.54 | 0.76 | 0.83 | 0.83 | 0.86 | 0.89 |
| 27  | Indicator power, kW          | Ni | 21.2 | 49.1 | 68.2 | 72.0 | 71.6 | 67.9 | 58.4 |
| 28  | Specific fuel consumption indicator, g/kW | Gi | 197 | 179 | 176 | 196 | 190 | 174 | 194 |
| 29  | Indicator efficiency          | th | 0.44 | 0.48 | 0.49 | 0.44 | 0.46 | 0.50 | 0.45 |
| 30  | Mechanical efficiency         | tm | 0.00 | 0.58 | 0.71 | 0.74 | 0.74 | 0.77 | 0.81 |
IOP Conf. Series: Earth and Environmental Science 688 (2021) 012013 doi:10.1088/1755-1315/688/1/012013

Table 3. Test results of the diesel engine D-240 when working with the regulator on a mixture of 75% rapeseed oil and 25% diesel fuel

| No. | Parameter name and dimension | Designation | Experiment number |
|-----|-----------------------------|-------------|------------------|
| 1   | Engine shaft rotation frequency, rpm | n | 2350 2300 2270 2200 2170 2000 1650 |
| 2   | The load on the brake, kg | Pt | 0 14.0 26.5 32.5 33.5 35.0 38.5 |
| 3   | Fuel consumption per experience, g | ДGt | 50 100 100 100 100 100 100 |
| 4   | Experience duration, s | T | 41 39 28.5 24.5 24.8 25.7 28.8 |
| 5   | Indications of a U-shaped manometer, mm | Δh | 160 159 156 146 145 132 91 |
| 6   | Oil pressure, MPa | Pm | 2.4 2.4 2.4 2.3 2.3 2.2 2.2 |
| 7   | Oil temperature, C° | tm | 77 82 86 88 91 93 95 |
| 8   | Coolant temperature, C° | tl | 74 75 77 80 81 82 84 |
| 9   | Exhaust temperature, C° | тg | 172 285 435 520 535 531 556 |
| 10  | Atmospheric pressure, kPa | Benv | 96 96 96 96 96 96 96 |
| 11  | Environment temperature, C° | Tenv | 21 22 22 22 23 23 |
| 12  | Hourly fuel consumption, kg/h | Gт | 4.4 9.2 12.6 14.7 14.5 14.0 12.5 |
| 13  | Cycle fuel supply, mg/cycle | gT | 15.6 33.4 46.4 55.7 55.7 58.4 63.1 |
| 14  | Air density, kg/m³ | ρenv | 1.1365 1.1325 1.1325 1.1325 1.1325 1.1286 1.1286 |
| 15  | Actual air consumption, kg/h | Ga | 324 323 320 309 308 294 244 |
| 16  | Theoretical air consumption, kg/h | GтAT | 381 373 368 356 352 324 267 |
| 17  | Filling ratio | ηV | 0.85 0.87 0.87 0.87 0.88 0.91 0.91 |
| 18  | Excess air ratio | a | 5.15 2.44 1.77 1.47 1.48 1.47 1.37 |
| 19  | Conditional average pressure of mechanical losses, MPa | Pч | 0.23 0.22 0.22 0.22 0.21 0.20 0.17 |
| 20  | Conditional power of mechanical losses, kW | Nч | 21.2 20.4 19.9 18.8 18.4 15.8 11.2 |
| 21  | Torque, N/m | Mt | 0 98 186 228 235 245 270 |
| 22  | Average efficient pressure, MPa | Pe | 0 0.26 0.49 0.60 0.62 0.65 0.71 |
| 23  | Efficient, kW | Ne | 0 23.6 44.1 52.4 53.3 51.3 46.6 |
| 24  | Specific efficient fuel consumption, g/kW h | gх | 391 286 280 272 273 268 |
| 25  | The unit cost of fuel, RUB./kWh | cG | 10.27 7.51 7.35 7.14 7.17 7.04 |
| 26  | Average indicator pressure, MPa | Pi | 0.23 0.48 0.71 0.82 0.83 0.85 0.88 |
| 27  | Indicator power, kW | Nт | 21.2 44.0 64.0 71.2 71.6 67.1 57.8 |
| 28  | Specific fuel consumption indicator, g/kW | gт | 207 210 197 206 203 209 216 |
| 29  | Indicator efficiency | nт | 0.42 0.41 0.44 0.42 0.43 0.42 0.40 |
| 30  | Mechanical efficiency | nч | 0.00 0.54 0.69 0.74 0.74 0.76 0.81 |

It can be seen from the test results that at a nominal engine speed of 2170 rpm, the efficient power of the engine running both on diesel fuel and on a mixture of rapeseed oil and diesel fuel is 53.3 kW. With the same torque of 235 N/m the efficient fuel mixture consumption is only 17 g/kW h more. At the same time, the unit cost of the fuel mixture is lower than that of diesel fuel.

This gives the reasons for using this mixture as a fuel in a diesel engine in terms of energy and cost parameters.
Conclusions
1. To ensure accurate dosing and uniform mixing of rapeseed oil and diesel fuel when producing fuel mixture for a diesel engine, a production line has been developed including the patented mechanism for mixing liquids of different viscosities.
2. A fuel mixture consisting of 75% rapeseed oil and 25% diesel fuel for a diesel engine has been prepared.
3. The comparative tests of the D-240 engine using diesel fuel and a fuel mixture of rapeseed oil and diesel fuel at the electric run-in-brake stand (KI-5543-GOSNITI) have been carried out.
4. The tests have shown that at a nominal frequency of engine crankshaft rotation (2170 rpm), the efficient power of the engine running both on diesel fuel and on a mixture of rapeseed oil and diesel fuel is 53.3 kW. With the same torque of 235 N/m the efficient fuel mixture consumption is only 17 g/kWh more. This fuel mixture is not inferior to mineral diesel fuel in terms of energy parameters.

References
[1] Zybalov V.S., Sergeev N.S., Zapevalov M.V. The rational use of rapeseed in agricultural production. AIC of Russia. 2019.V.26. No.2.
[2] Zybalov V.S., Kozhamkulova Ya.S. Analysis of chemical composition and physical properties of sunflower and rapeseed oil. Chelyabinsk: ChGAA, 2013. P. 33-38.
[3] Zybalov V.S. Spring rapeseed is a culture of great opportunities in the Southern Urals. AIC of Russia. 2019.Vol. 26, No.5 p. 755-762.
[4] Winter and spring rape (practical guide), Moscow: State Agricultural Committee, 1988. 44 p.
[5] Markov V.A. et al. Rapeseed oil as an alternative fuel for diesel. V.A. Markov, A.I. Gaivoronskiy, S.N. Devyanin, E.G. Ponomarev. Automotive Industry, 2006, No. 2.
[6] Zhosan A.A., Ryzhov Yu.N., Kurochkin A.A. Comparative physical and chemical properties of diesel fuel from rapeseed oil. Engineering support for the development in the agricultural sector. Orel State Agrarian University, P. 11.
[7] Patent for invention No. 2342985, RF. Mixing device for liquids with different viscosity. Zapevalov M.V., Sergeev N.S., Marinin S.P. Publ. 10.01.2009.