Biodiesel Fuel Based on Rapeseed Oil

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Abstract. Many countries, including the Russian Federation, conduct research on replacing mineral fuel with environmentally friendly energy. One of these types can be a 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, lanterns were used to light the streets and lubricate metal parts in contact with water and steam to prevent corrosion. It is currently used in hydraulic systems of tractors and agricultural machines. The study aims to determine 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 mm\textsuperscript{2}/s, rapeseed oil viscosity is 75.1 mm\textsuperscript{2}/s. The mixture consisting of 75% rapeseed oil and 25% diesel fuel has a thickness of 36.0 mm\textsuperscript{2}/s, and the density and lower combustion heat are close to the 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 mix of 75% rapeseed oil and 25% diesel fuel. The authors find that at a nominal frequency of engine crankshaft rotation (2,170 rpm), the engine efficient power is 53.3 kW, running both on diesel fuel and on a mixture of rapeseed oil and diesel fuel. 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.

Keywords: Oil crop · Rapeseed oil · Biodiesel fuel · Property · Production line · Efficiency · Experiment · Comparative parameter

1. Introduction

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

The demand for vegetable oils is growing in many countries worldwide, including the Russian Federation. In this regard, the cultivated area of oil crops increases, and their cultivation technology is improved. In the Chelyabinsk region, the spring rapeseed area varies from 30 to 50 thousand ha over the years in the sphere of oil crop growing. Due to its faulty cultivation technology, the average seed yield does not exceed 11 kg/ha. However, the Southern Urals’ climatic conditions enable them to obtain profits...
up to 20 kg/ha. The area of oil crops, including rapeseed, amounted to 205.5 thousand hectares in the Chelyabinsk region in 2019 [5].

Agricultural production is associated with high energy costs. This primarily relates to fuel and lubricants. In crop cultivation technology, the average fuel consumption per hectare is about 50 kg of diesel fuel in Russia. It should be noted that the share of fuel cost in the cost price of cultivated agricultural products exceeds 20%. Thus, increasing fuel prices leads to the growth in farm products’ value, while the price containment in the market leads to a decrease in the economy [7].

Russia is one of the leading suppliers of natural energy resources to the world market. The stock of these resources is not unlimited; therefore, studies related to alternative energy sources are being carried out worldwide. There is an essential issue of replacing mineral fuel with another one that will be environmentally friendly. One of these types, particularly for agriculture, can be a biodiesel fuel based on vegetable oils [6].

Extensive research focused on 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. Suppose one unit of methanol is added to nine mass units of vegetable oil under certain conditions (due to a chemical reaction). In that case, methyl ester and glycerin are formed. The methyl ester is a biofuel. There are some other ways to prepare it, for example, by neutralizing glycerol [1].

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%); nicotinic (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, lubricate metal parts in contact with water and steam to prevent corrosion. It is currently used in hydraulic systems of tractors and agricultural machines. It is also an excellent raw material for producing 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 the soil or water, it does not harm 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 mineral diesel fuel combustion. 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 increase the fuel pump's life and the engine itself [2]. 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 mineral diesel fuel's purchase price.

Objective: To determine the diesel engine’s comparative operational parameters 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 schedule 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.

2. Materials and Methods
Despite the differences in rapeseed oil and diesel fuel (table 1), rapeseed oil is currently being used more and more as the main component in producing biodiesel fuels. These two components mix well, and the resulting mixture has properties that help it 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 thickness 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.

### 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%-the residue, not more than, % | 0.4          | 0.3        |

3. 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 variety 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 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).

![Figure 1. Scheme of production line for fuel mixture preparation.](image)

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), liquid 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 three from containers 1 and 2 through pipelines 5 to boxes 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 gravity force's return pipe. When the fluid mixer nine is turned on, the solenoid valves seven are opened, and the fluids enter the slotted fluid dispensers eight dosings in a particular 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 [3]. 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   | Engine shaft rotation frequency, rpm | n           | 2,350 2,300 2,270 2,200 2,170 2,000 1,650 |
| 2   | The load on the brake, kg      | Pt          | 0 17.0 29.0 33.0 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      | Bₐav        | 96 96 96 96 96 96 |
| 11  | Environment temperature, °C    | Tₑav        | 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    | gr          | 14.8 31.8 44.1 53.5 52.2 49.2 57.2 |
| 14  | Air density, kg/m³             | ρₑav        | 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 |
| 17  | Filling ratio                  | hV          | 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  | The conditional average pressure of mechanical losses, MPa | Pₐm | 0.23 0.22 0.22 0.22 0.21 0.20 0.17 |
| 20  | Conditional power of mechanical losses, kW | Nₑ | 21.2 20.4 19.9 18.8 18.4 15.8 11.2 |
| 21  | Torque, N/m                    | Mₑ          | 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 | gₑ         | 306 249 265 255 227 240 |
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 | 2,350 2,300 2,270 2,200 2,170 2,000 1,650 |
| 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 | ΔGt | 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 | tg | 172 285 435 520 535 531 556 |
| 10  | Atmospheric pressure, kPa | B_{atm} | 96 96 96 96 96 96 96 |
| 11  | Environment temperature, °C | T_{env} | 21 22 22 22 22 23 23 |
| 12  | Hourly fuel consumption, kg/h | Gt | 4.4 9.2 12.6 14.7 14.5 14.0 12.5 |
| 13  | Cycle fuel supply, mg/cycle | Gf | 15.6 33.4 46.4 55.7 55.7 58.4 63.1 |
| 14  | Air density, kg/m³ | p_{env} | 1.1363 1.1325 1.1325 1.1325 1.1325 1.1286 1.1286 |
| 15  | Actual air consumption, kg/h | G_A | 324 323 320 309 308 294 244 |
| 16  | Theoretical air consumption, kg/h | G_{AT} | 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  | The conditional average pressure of mechanical losses, MPa | Pm | 0.23 0.22 0.22 0.22 0.21 0.20 0.17 |
| 20  | Conditional power of mechanical losses, kW | Nm | 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/kWh | g_f | 391 286 280 272 273 268 268 |
4. Discussion

It can be seen from the test results that at a nominal engine speed of 2,170 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.

5. Conclusion

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 (2,170 rpm), the engine's efficient power runs on diesel fuel, and 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.

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