Vegetal fuel as environmentally safe alternative energy source for Diesel engines

A K Apazhev, Y A Shekikhachev, V I Batyrov, R A Balkarov, Kh B Kardanov, Kh L Gubzhokov and A I Bolotokov
Mechanization and enterprises power supply department, Kabardino-Balkarian State Agrarian University named after V. M. Kokov, 1c, Lenin Aveю, Nalchik, 360030, Russia
E-mail: shek-fmep@mail.ru

Abstract. Oil crisis and sharp increase of oil and petroleum market prices, resource limitation fastened the search for alternative energy sources. Among alternative energy sources renewable and especially received from vegetable biomass (fuel alcohol, vegetable oils) are of the greatest interest. With the account of this the article gives the results of studying the peculiarities of the bio-Diesel operational cycle and possibilities to adapt existing Diesels to biofuel. It has been determined that substitution of the Diesel fuel (DF) with rape-seed oil (RSO) and biofuel increases maximal and intermediate injection pressure, earlier start and greater injection duration, loss in frequency and oscillatory amplitude in the pressure pipeline after completing the injection. When RSO is used there appear increased inside lacquer film on the blowgun; which results in the needle valve immobility down to hanging up; needle valve immobility leads to the time lag of inlet and lengthening of the injection, increase in maximal injection pressure. There is quality loss of spraying the fuel, increase in non-uniformity and medium volume diameter of fuel drops, as well as penetration of the fuel jet into the air medium. Higher viscosity of the biofuel increases the injection rate due to leakage decrease in plunger pairs of diesel fuel injection pumps (DFIP).

1. Introduction
Ethylic alcohol (EA), vegetable oils made from crops, and methyl alcohol (MA) both from wood and its wastes are the best in economic terms [1, 2]. Fuel alcohol and vegetable oils can be used to substitute partially or fully traditional motor fuels (petroleum and Diesel). Biofuel from VO and alcohols are of especial interest and can fully substitute petroleum product fuels. It is also important that biofuel allow saving oil fuels and improve ecological qualities of engines.

Energy value of vegetable oils per kilogram is 37…40 mJ, while Diesel fuels typically have 42…46 mJ. Despite insignificant difference in energy value, vegetable oil density (0.91…0.94 kg/l) is higher than that of Diesel fuel (0.82…0.86 kg/l).

Vegetable oils have greater kinematic viscosity (7.5…10 times), that is why they dissipate worse. Cetane number of the vegetable oils on average is 16% lower than of the Diesel fuel (DF).

Basing on the combination of the physico-chemical and economical parameters RSO can be recommended as a basis for biofuel.

There are three trends of studying biofuel production from RSO and its application:

- possibility to use pure RSO or in combination with DF(RSO+DF);
RSO biofuel with EA or MA additives (RSO+EA, RSO+MA);
• biofuel production by processing RSO into complex ethyl- and methylesters (REE, RME).

Nowadays most developed countries conduct researches on RSO biofuel production. France has produced ecologically pure fuel based on RSO which is named “Diestro” [1, 2]. “Diestro” was used in tractors and cars. The results showed up to 50% decrease in soot emission.

The economic alliance “EurobioDiesel” (France, Germany, and Italy) is developing a new kind of fuels from RSO and glycol alcohol monoethers. Glycol alcohol monoethers are received from sunflower and soy oil.

“John Deer” (the USA) tested biofuel Diesel made from oil, butanol and ethanol. The biofuel included oil 53.3%, ethanol 13.3%, butanol 33.4%, triethylanine 3.3% and lanolin acid. It has been determined that operating on the biofuel Diesel capacity remained the same despite decreased by 19% combustion heat in comparison with DF [3].

“Deitz” company Diesel (Germany) F3L413W had good results. It operated on the mixture of 40% DF, 40% RSO, 19% water and 1% of emulsifier agent. According to the expertise to use this composition on a common scale it is necessary to solve some problems: soot prevention on the piston head, a head and a valve, an injection nozzle tip; better pulverization of a more viscous fuel [4].

Streyr WD209 Diesel has been tested in Australia which was a combination of rape seed oil with Diesel fuel in different proportions.

The issue of producing vegetal biofuel is also studied in our country [5]. The studies have showed that when Diesel D-240 operates on biofuel (75% RSO+25% DF) there is no decrease in its capacity and fuel efficiency; there is a decrease in the concentration of harmful substances with exhaust fumes: carbonic oxide by 55%, hydrocarbons by 2…5 times. The results of the study prove applicability of RSO as a component of the composite fuel from the point of view of the economy and ecology.

2. Materials and methods
The physical parameters of DF, biofuel composites based on RSO, DF and alcohols were determined with common laboratory devices and facilities [6-9]. Density was measured with a densitometer graduated in 0.001 g/sm³, kinematic viscosity with a capillary glass fluiditymeter, surface tension with a Rehbinder gauge, flash temperature with a TTH-1, sulfur content with a lamp method. Experimental tests were done on the motorless and motored testing facilities with fuel injection equipment assemblages of a Diesel engine D-240 and SMD-62. Hydraulic characteristics of the high pressure fuel system elements (HPFS) were determined on the testing facilities KI-22201 with the add-on device KI-15713.

HPFS section adjustment was at fuel temperature in the pump head 40°C with pressure 0.1 MPa. Then a geometrically effective plunger stroke and geometric commencement of fuel delivery with spillage under pressure 2.4 MPa were determined. Geometrically effective plunger stroke was determined with an indicator graduated in 0.01 mm, spillage pressure was controlled with a manometer graduated in 0.2 MPa. The tests were conducted on the testing facilities “Hartridg-1100” with a fuel pump (FP) UFP-5. The facility allows stepless changing of the drive shaft rotation frequency from 0 to 4200 min⁻¹, controlling pressure in the FP pump head, supporting test temperature specifications with the automatic temperature controller. After adjusting DFIP section a cyclic inlet and an onset angle of the fuel injection were determined with the stroboscoping light of the testing facility.

3. Results discussion
Physico-chemical properties of the fuel in the engine greatly determine its power, economy and ecological parameters. A final decision on biofuel usage as an alternative to the traditional DF must be done on the results of motor tests on the test facilities and operational tests.

To choose the most perspective and cheap energy material as a base for biofuel we compared the most important characteristics of different vegetable oils and commercial DF (Table 1).

| Table 1. | Physico-chemical properties of the vegetable oils and Diesel fuel |
### Parameters

|                | rape   | Oil  | soya | cotton | Diesel fuel |
|----------------|--------|------|------|--------|-------------|
| Fuel lower heating value, kJ/kg | 37300  | 36400| 35400| 42500  |
| Fuel density, kg/m³ | 920    | 920  | 920  | 840    |
| Viscosity at 20°C, mm²/s | 75     | 57   | 72   | 6      |
| Cetane rating | 32-36  | 36-39| 35-38| 45     |
| Wijs          | 97     | 130  | 105  | 6      |
| Acidity, mg Potassium hydroxide/100 ml | 0.04 | 0.70 | 0.09 | 5.0    |
| Surface tension, din/s | 35.8   | 35.8 | 35.5 | 26…30 |
| Temperature, °C: |        |      |      |        |
| blushing       | -9     | -4   | -1   | ≤0     |
| hardening      | -18    | -9   | -3   | ≤-7    |
| colliquation   | -15    | +4   | +14  | ≤0     |
| filtrability   | +15    | +4   | +14  | ≤0     |

The motorless and motor tests of the biofuel composites test samples based on RSO, DF and alcohols (ethyl – EA, methyl – MA) (tables 2, 3), peculiarities of the biodiesel operational cycle have been studied as well as possibilities to adapt existing Diesel engines to biofuel.

### Table 2. Elementary composition of basic and composite fuels

| Fuel                         | C   | H   | O   | N   | S   |
|------------------------------|-----|-----|-----|-----|-----|
| Diesel fuel (DF)             | 0.870| 0.126| 0.004| 0.002|
| Rape seed oil (RSO)          | 0.780| 0.100| 0.120| 0.000|
| Ethanol (EA)                 | 0.522| 0.130| 0.370| 0.000|
| Methanol (MA)                | 0.375| 0.125| 0.500| 0.000|
| 75% RSO+25% DF               | 0.802| 0.106| 0.091| 0.000|
| 50% RSO+50% DF               | 0.825| 0.113| 0.062| 0.000|
| 90% RSO+10% EA               | 0.754| 0.103| 0.145| 0.000|
| 70% RSO+30% EA               | 0.700| 0.110| 0.194| 0.000|
| 90% DF+10% MA                | 0.820| 0.126| 0.054| 0.0018|
| RSOE                         | 0.770| 0.110| 0.110| 0.006|

### Table 3. Basic and composite fuel characteristics

| Fuel                         | Fuel lower heating value, kJ/kg | Density, kg/m³ | Cetane rating | Fuel viscosity at 20°C, mm²/s | Weight coefficient, kg/kg |
|------------------------------|---------------------------------|-----------------|---------------|-------------------------------|---------------------------|
| Diesel fuel (DF)             | 42500                           | 840             | 45            | 6                            | 14.35                     |
| Rape seed oil (RSO)          | 37300                           | 920             | 36            | 75                           | 12.00                     |
| Ethanol (EA)                 | 26500                           | 790             | 9             | 2                            | 8.55                      |
| Methanol (MA)                | 19665                           | 795             | 5             | 0.55                         | 6.52                      |
| 75% RSO+25% DF               | 38600                           | 900             | 38            | 38.2                         | 12.56                     |
| 50% RSO+50% DF               | 39900                           | 880             | 40            | 39.8                         | 13.20                     |
| 90% RSO+10% EA               | 36356                           | 902             | 33            | 39.5                         | 11.65                     |
| 70% RSO+30% EA               | 34383                           | 890             | 27            | 27.2                         | 10.97                     |
| 90% DF+10% MA                | 40216                           | 835             | 41            | 5.4                          | 13.56                     |
| RSOE                         | 37000                           | 884             | 52            | 7.6                          | 12.70                     |
Table 4. Changes in engine power depending on the combined fuel composition

| Fuel                          | Calorific efficiency, mJ/kg | Engine capacity, kW | PC, % |
|-------------------------------|------------------------------|---------------------|-------|
| Diesel fuel (100%)            | 42.8                         | 19.9                | 32.0  |
| DF+RSO (75%+25%)              | 41.3                         | 19.4                | 32.4  |
| DF+RSO (50%+50%)              | 39.9                         | 19.2                | 31.7  |
| DF+RSO (25%+75%)              | 38.5                         | 18.9                | 32.4  |

It has been determined that the decrease of Diesel capacity with vegetable oil in comparison with DF was below 10% (table 4) [10].

Experimental tests of Diesel D-240 and SMD-62 operating with RSO and composition of RSO with DF (75% + 25% DF) showed that Diesel D-240, with the combustion chambers similar to the chamber “CCRD1” adapts better to RSO and biofuel in comparison with the Diesel engine SMD-62, with the direct injection.

Operating on biofuel compositions Diesel keeps its operational qualities. Diesel capacity and efficiency decrease proportionally to power capacity and cyclic fuel inlet.
Shown in figure 1 regulatory Diesel characteristics D-240 operating on DF and biofuel composite (75% RSO+25% DF) prove that at constant regulations of fuel injection equipment running torque reserve coefficient when operating on biofuel is higher (11.5 %), than with DF (9.88 %). Diesel D-240 peak capacity when operating on biofuel composite is 2 % lower (56.8 kW) comparing to DF (58.0 kW). Regulatory irregularity degree when operating on biofuel (3.87 %) and DF (2.79 %) differ insignificantly.

Usage of RSO as fuel, or biofuel based on RSO combined with DF or alcohols introduces significant changes into the burning process. Biofuel have less Cetane rating that is less autoignition. That is why the ignition lag increases. As studies show [10], despite the ignition lag increase, Diesel operating on biofuel, have lower pressure rise rates and less intensity of heat generation.

Sluggish combustion at the first (kinetic stage) complicates fuel burning in the main (diffusive stage) and increases its duration. It increases the total period of burning and worsens Diesel indicated efficiency.

Quality analysis of the biofuel burning process is proved by the data of Diesel D-240 tests on the test operating on different fuels (figure 2).

At augmented intermediate rating of Diesel D-240 the peak capacity when using biofuel is higher by 7.69 % at \( n = 0.85n_{\text{max}} \) (figure 3) and by 4.34% at \( n = 0.7n_{\text{max}} \) (figure 4). The lowest fuel consumption rate when applying biofuel is higher by 3% at \( n = 0.85n_{\text{max}} \) and by 7.93% at \( n = 0.75n_{\text{max}} \).

**Figure 3.** Partial regulatory engine parameters D-240 operating on:

- --- Diesel fuel;
- _ _ _ _ _ biofuel (75% RSO+25% DF)

**Figure 4.** Partial regulatory engine parameters D-240 operating on:

- --- Diesel fuel;
- _ _ _ _ _ biofuel (75% RSO+25% DF)
Application of biofuel blends based on RSO and ethylic alcohol (EA) keeps Diesel functional properties at some worsening of power and economic parameters which is proportionally lower to the calorific value of the applied fuels (figure 5). At the same time Diesel toxic parameters significantly improve: soot content decreases by 50%, nitric oxide by 12%.

4. Conclusion
The following conclusions can be made:
1. Fossil fuel shortage can be solved by biomass fuel. Rape seed oil is recommended as a base for biofuel.
2. The comparative analysis of physico-chemical and cost parameters of different biofuel blends allows recommending the blend RSO with ethylic alcohol as the most perspective biofuel. Additives can be recommended up to 30% of the volume. Further increase of the alcohol additive decreases nitric oxide effect in the Diesel exhaust fumes and increases combustion period.
3. Operating on the biofuel Diesel keeps its functional properties. Diesel capability and efficient performance here scale down depending on energy intensity decrease and cyclical fuel inlet. To rehabilitate power and economic parameters it is necessary to increase cyclical feed and lead angle of the fuel injection.
4. EA additive into RSO allowed significant increase (more than 2 times) and RSO viscosity decrease. But, biofuel blends are steel highly viscous and overcome DF viscosity by 5…7 times, that needs additional heating of the biofuel or external heating of the injector.
5. Toxicity components content (\(N_{\text{ox}}\) and soot) with biofuel decreases significantly in comparison with their content in Diesel EF operating on DF (soot content decreases by 50%, nitric oxide by 12%).

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