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SAFFLOWER OIL AS A BIOLOGICAL COMPONENT OFBLENDED FUEL FOR DIESEL ENGINES

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Abstract

One of the types of motor biofuels for diesel engines is blended fuel obtained by mixing petroleum diesel and vegetable oils. One of these oils can be safflower oil produced from the seeds of Carthamnus tinctorius. The main physical, chemical, and calorific properties were studied for the safflower oil and for its blends with petroleum diesel oil. The results of bench dynamometer tests of D-243 diesel engine (four-stroke, four-cylinder, direct injection, compression ignition engine), running on safflower biodiesel blends, are presented. The proportions of safflower oil and diesel oil in the fuel blends were 20/80, 25/75, 33/67, and 50/50. Moreover, the blended fuel 50/50 was processed with 25 kHz ultrasonic emitting. When the diesel engine was running on blended fuel, brake power decreased by 1-4 percent, brake specific fuel consumption increased by 4-10 percent, while the exhaust smoke opacity was less by 10-40 percent compared to the engine operation on the petroleum diesel oil. The processing of the fuel blend 50/50 with ultrasonic allows improving engine power capacity, efficiency, and smoke opacity compared to the engine operation on unprocessed blended fuel.

Key words: *biodiesel, blended fuel, diesel engine, safflower oil, ultrasonic.*

INTRODUCTION

A perspective source of heat energy for automotive diesel engines is biodiesel.

One of the types of motor biofuel is blended fuel obtained by mixing of petroleum diesel oil and vegetable oil when the second one performs functions of biological component (Kampmann, 1993; Fajman and Ondracek, 1999; Dorado et al., 2002; Megahed, 2004; Campbell et al., 2008; Ukhanov et al., 2009a; 2011).

The most studied biological components of blended fuel are rapeseed oil, camelina oil sunflower oil and mustard oil (McDonnell et al., 1995; 2000; Niemi et al., 1998; Moreno et al., 1999; Erdiwansyaha et al., 2019). However, other types of vegetable oils have technological, calorific, physical and chemical properties not worse than the aforementioned oils.

One of these types is safflower oil produced from the seeds of *Carthamnus tinctorius* (Ukhanov et al., 2016).

MATERIALS AND METHODS

Safflower (*Carthamnus*) is a genus of annual, biennial and perennial herbs from the Asteraceae family. The average yield of safflower seeds is 1.5-2.2 tons per hectare, the oiliness is 45-50%.

For evaluation of physical, chemical, and calorific properties of safflower oil and blended safflower-diesel fuel, a series of laboratory tests and theoretical studies was performed. The studies included a definition of the following parameters: fatty acids content, hydrocarbons content, lower calorific value, density, kinematic viscosity and dynamic viscosity.

Definition of fatty acids content in the safflower oil was based on the results of the analysis with chromatographic tester «Kristall-2000».

On the grounds of fatty acids content, an average chemical formula and average molar mass of safflower oil were calculated. According to obtained data, hydrocarbons content and lower calorific value of safflower oil were identified.

The lower calorific value of blended safflower-diesel fuel (MJ/kg) with a percentage of biofuel and diesel 20/80, 25/75, 33/67, 50/50 was calculated by modified Mendeleev's formula (1):

$$H_u = K_D \cdot [34{,}013C_D + 125{,}6H_D - 10{,}9(O_D - S_D) - 2{,}512(9H_D + W_D)] + K_{SaffOil} \cdot [34{,}013C_{SaffOil} + 102{,}452H_{SaffOil} - 10{,}9O_{SaffOil}] \quad (1)$$

where: K_D, $K_{SaffOil}$ are contents (mass portions) of petroleum diesel oil and safflower oil in blended fuel (at any ratio of components $K_D + K_{SaffOil} = 1$); C_D, H_D, O_D, S_D, W_D are contents of carbon, hydrogen, oxygen, sulphur and water in petroleum diesel oil; $C_{SaffOil}$, $H_{SaffOil}$, $O_{SaffOil}$ are contents of carbon, hydrogen and oxygen in safflower oil.

The density of the safflower oil and safflower-diesel fuel at the different ratios of biological and petrochemical components was measured with vibration meter VIP-2M. Kinematic viscosity was determined with capillary viscometer VPZh-2 by Pinkevich. Dynamic viscosity was measured with micro-viscometer «HAAKE».

For evaluation of the influence of blended fuel (unprocessed and processed with ultrasonic) on diesel engine power capacity, fuel economy and ecological parameters, the bench dynamometer tests were completed.

The tests were performed on an experimental motor setup (Figure 1) including D-243 tractor diesel engine (four-cylinder, four-stroke, direct injection, compression ignition engine). Its fuel supply system was equipped with an ultrasonic mixer.

Figure 1. Experimental motor setup: 1 - D-243 diesel engine with the set of instruments; 2 - PC

The engine was coupled with KS-56/4 dynamometer brake including the remote controller, air and fuel flow meter and PC equipped with the integral analogue-to-digital converter of signals. The gas analyser «AVTOTEST CO-CH-D» was used for measuring of engine's exhaust smoke opacity.

The treatment of blended fuel with ultrasonic vibrations at the emitting frequency 25 kHz was performed during the engine operation with the help of an ultrasonic mixer (Ukhanov et al., 2014a; 2017; Ukhanova et al., 2017a) built in the fuel supply system (Ukhanov et al., 2009b; 2013; 2014b; 2017b). The input channel (3) of mixer housing (2) (Figure 2) is connected with the fuel filter, the outlet channel (4) - with a high-pressure fuel pump. A piezo emitter (1) is placed in the inner chamber of the housing (2) and connected with the electronic control unit (5) which is coupled with the 12V voltage power source.

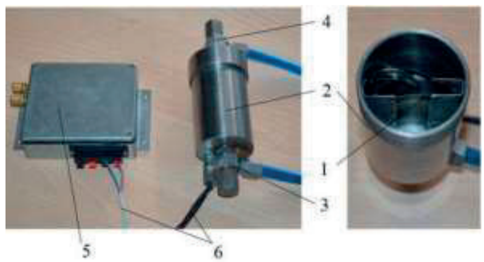

Figure 2. Ultrasonic mixer: 1 - piezo emitter; 2 - housing; 3, 4 - input and outlet channels; 5 - electronic control unit; 6 - electric wires

The performance of the diesel engine was evaluated with the following parameters: brake power (BP), hourly fuel consumption (HFC), brake specific fuel consumption (BSFC) and exhaust smoke opacity.

RESULTS AND DISCUSSIONS

The petrochemical component of blended fuel was conventional diesel oil DT-L-62 containing carbon 0.870, hydrogen 0.126, oxygen 0.004. The lower calorific value (LCV) of diesel oil was 42.4 MJ/kg, density 830 kg/m^3, kinematic viscosity 4.2 mm^2/s, dynamic viscosity3 MPa·s (at 20° C).

The biological component of blended fuel was safflower oil containing carbon 0.775, hydrogen 0.115, oxygen 0.110. The LCV of safflower oil was 36.99 MJ/kg, density 920 kg/m^3, kinematic viscosity 67.3 mm^2/s, dynamic viscosity 58.3 MPa·s (at 20°C).

The results of evaluation physical, chemical and calorific parameters of blended fuel with a ratio of biofuel and diesel 20/80, 25/75, 33/67, 50/50 are presented in Table 1.

Table 1. Physical, chemical and calorific parameters of blended safflower-diesel fuel

Blended fuel	Element's content (carbon, hydrogen and oxygen)	Lower calorific value, MJ/kg	Density, kg/m^3	Kinematic viscosity, mm^2/s	Dynamic viscosity, MPa·s
20% SaffOil + 80% Diesel	C = 0.851; H = 0.124; O = 0.025	41.44	843	8.2	16.8
25% SaffOil + 75% Diesel	C = 0.846; H = 0.123; O = 0.031	41.14	850	8.4	17.5
33% SaffOil + 67% Diesel	C = 0.839; H = 0.122; O = 0.039	40.68	858	9.3	19.5
50% SaffOil + 50% Diesel	C = 0.822 H = 0.121 O = 0.057	39.81	867	12.2	23.6

From the analysis of Table 1, it follows, that the blended safflower-diesel fuel has slightly worse parameters of the physical, chemical and calorific properties compared to the conventional (petroleum) diesel oil.

As a result of research, experimental data of power capacity, fuel economy and ecological parameters were obtained when the diesel engine was running at the external speed characteristic on blended fuel with percentage (ratio) of biological and petrochemical components 20/80, 25/75, 33/67 and 50/50.

Analysis of the results of bench tests shows that as the content of safflower oil in blended fuel increases, the engine brake power slightly decreases (Figure 3). For example, when running at nominal mode at crankshaft speed 2200 rpm on blended fuel 20/80, BP reduced from 61 kW to 60.4 kW (by 1%). On blended fuel 50/50 BP reduced to 58.8 kW (by 4%). The obtained reduction of BPcan is explained by the lower calorific value of blended fuel which is less than the LCV of the conventional diesel oil.

During the engine operation on blended safflower-diesel fuel, its fuel economy worsens. As the content biological component in blended fuel increases, the hourly fuel consumption and BSFC are larger. For example, when the engine was running at a rated speed 2200 rpm on fuel 20/80, the hourly fuel consumption increased from 14.6 kg/h to 15.1 kg/h (by 3%). On fuel 50/50 it increased to 15.6 kg/h (by 6%). The growth of HFC, when the portion of safflower oil in the blended fuel is increasing, can be explained by the growth of cyclic fuel supply. It happened due to increasing of mass supply of the blended fuel in over-plunger chamber of the fuel pump.

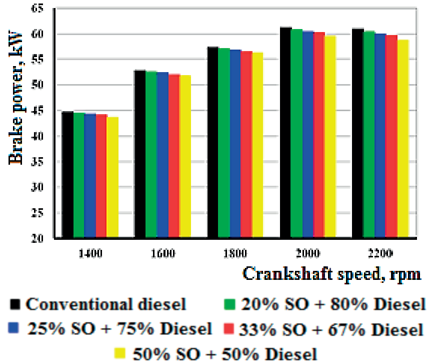

Figure 3. The change of diesel engine brake power depending on the crankshaft speed when running on conventional fuel and blended safflower-diesel fuel

Brake specific fuel consumption increases as the content of safflower oil in the blended fuel is larger (Figure 4).

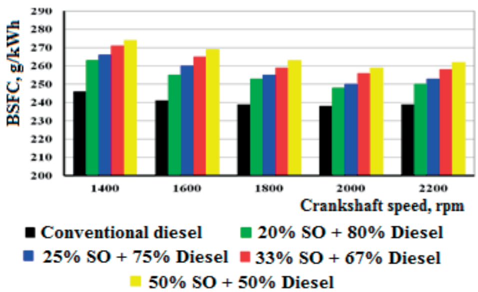

Figure 4. The change of BSFCdepending on the crankshaft speed when running on conventional fuel and blended safflower-diesel fuel

For example, when the diesel engine was running at the rated mode on the blended fuel 20/80, BSFC was 250 g/kWh, on the fuel50/50 it was 264 g/kWh. It was by 5−10% larger than on the conventional diesel fuel (239 g/kWh).

As the crankshaft speed and percentage of safflower oil increase, the exhaust smoke opacity decreases (Figure 5). The maximum value of the smoke opacity (0.6) was noted at the engine operation on the conventional diesel oil and crankshaft speed 1400 rpm. At the maximum torque (crankshaft speed 1600 rpm) the smoke opacity on blended fuel was 0.36-0.43, while on the conventional fuel it was 0.53. The minimum value (0.26) was obtained during the engine operation on blended fuel 50/50 at 2200 rpm. The reduction of the exhaust smoke opacity during the engine operation on safflower-diesel fuel can be explained by less content of carbon compared with conventional diesel oil.

Thus, the greatest deterioration of the power capacity and fuel economy was obtained during the diesel engine operation on safflower-diesel fuel 50/50, but this kind of fuel promoted the maximum reduction of the exhaust smoke opacity.

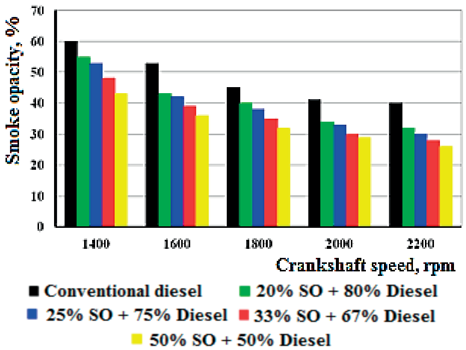

Figure 5. The change of exhaust smoke opacitydepending on the crankshaft speed when running on conventional fuel and blended safflower-diesel fuel

To improve the diesel engine power capacity, fuel economy and ecological parameters, the safflower-diesel fuel 50/50 was processed with an ultrasound treatment by ultrasonic mixer imbedded in the fuel supply system. Due to the cavitation process, the ultrasonic mixer promoted qualitative mixing of biological and petrochemical components. Moreover, in consequence of high-frequency vibrations, radicals of hydrocarbon groups separated from some fatty acids and joined to the other acid's molecules (Ukhanov et al., 2015).

From the analysis of Figure 6 it follows that during the operation on the ultrasonic processed safflower-diesel fuel, the engine efficiency is worse than on the conventional diesel oil, but better than on the unprocessed blended fuel. For example, the brake power at the nominal mode increased from 58.8 kW to 59.7 kW due to the ultrasonic treatment of blended fuel 50/50. It is only 2% less than at the engine operation on the conventional diesel oil.

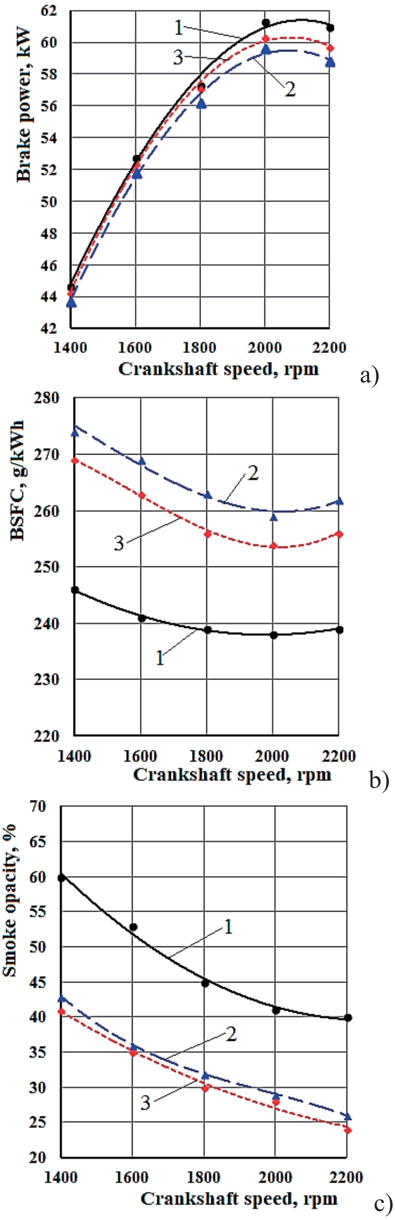

Figure 6. The change of the diesel engine parameters at the external speed characteristic: a) brake power; b) BSFC; c) exhaust smoke opacity;
1 - conventional diesel oil; 2 - unprocessed blended fuel 50/50; 3 - ultrasonic processed fuel 50/50

The brake-specific consumption of the ultrasonic processed fuel reduced by 3% in comparison with the unprocessed fuel. It was 256 g/kWh, which is 7% more than at the engine operation on the conventional diesel oil.

The exhaust smoke opacity also decreases on ultrasonic processed safflower-diesel fuel. At the nominal mode on fuel 50/50 without ultrasonic, the smoke opacity reduces from 0.4 to 0.26, with ultrasonic - to 0.24.

The obtained results show improvement of the engine power capacity, fuel economy and ecological parameters due to the ultrasonic treatment of the blended fuel.

It should be noted that the blended fuel can be used not only as a motor fuel but also as an activator injected at the intake stroke into the diesel engine's intake manifold for the fumigation of air charge, which promotes improving the environmental parameters (Ukhanov et al., 2019; Ryblov et al., 2018; 2019; 2020).

CONCLUSIONS

The main parameters of physical, chemical and calorific properties of the safflower oil, as a biological component of the blended safflower-diesel fuel, were evaluated. The lower calorific values 36.99 MJ/kg, density 920 kg/m^3, kinematic viscosity 67.3 mm^2/s, dynamic viscosity 58.3 MPa·s (at 20° C).

For blended safflower-diesel fuel with percentage (ratio) of biological and petrochemical components 20/80, 25/75, 33/67, 50/50, these parameters are: the lower calorific value from 39.81 to 41.44 MJ/kg, density from 843 to 867 kg/m^3, kinematic viscosity from 8.2 to 12.2 mm^2/s, dynamic viscosity from 16.8 to 23.6 MPa·s (at 20°C).

The results of the bench dynamometer tests show that during the diesel engine operation on the blended safflower-diesel fuel the brake power decreases by 1−4%, the brake-specific fuel consumption increases by 4-10% in comparison with the engine operation on the conventional petroleum fuel. The greatest decline of the power capacity and deterioration of the fuel economy was obtained during the engine operation on the blended fuel 50/50. However, the maximum reduction of the exhaust smoke opacity was obtained on this kind of fuel.

The ultrasonic treatment of safflower-diesel fuel 50/50 allows improving the power capacity, fuel economy and ecological parameters of the diesel engine during its operation on the blended fuel.

REFERENCES

Campbell, J.E., Lobell, D.B., Genova R.C., Field, C.B. (2008). The Global Potential of Bio-energy on Abandoned Agriculture Lands. *Environ. Sci. Technol.* 42(15), 5791–5794.

Dorado, M.P., Arnal, J.M., Gomez, J. et al. (2002). The effect of a waste vegetable oil blend with diesel fuel on engine performance. *Trans. ASAE*, 45(3), 519-523.

Erdiwansyaha, Mamat, R., Sani, M.S.M. et al. (2019). An overview of Higher alcohol and biodiesel as alternative fuels in engines.*Energy Reports*, 5, 467-479.S

Fajman, M., Ondracek, J. (1999). Practical Experience in Using Biodegradable Fillings in Zetor Tractors. *Zemed.Techn*., 45(4), 155-158.

Kampmann, H.J.(1993) Dieselmotor mit Direkteinspritzung fur Pflanzenol. *MTZ*, 54(7/8), 378-383.

McDonnell, K.P., Ward, S.M., Timoney, D.J. (1995). Hot water degummed rapeseed oil as a fuel for diesel engines. *J.agr.engg Res*., 60(1), 7-14.

McDonnell, K.P., Ward, S.M., McNulty, P.B., Howard-Hildige, R. (2000). Results of engine and vehicle testing of semirefined rapeseed oil. *Trans.ASAE*, 43(6), 1309-1316.

Megahed, O.A. (2004). Rapeseed OilEsters as Diesel Engine Fuel. *Energy Sources*, 2, P.119-126.

Moreno, F., Munoz, M., Morea-Roy, J. (1999). Sunflower methyl ester as a fuel for automobile diesel engines. *Trans.ASAE*, 42(5), 1181-1185.

Niemi, S.A., Hatonen, T., Laiho, V.O.K. (1998). Results from a Durability Test of a Mustard Seed Oil Driven Tractor Engine. *SAE Technical Paper Series*, 982528, 1-15.

Ryblov, M.V., Ukhanov, D.A. Ukhanov, A.P. (2018). Developing the Automatic System for the Multi-Point Fumigation of Air Charge in the Diesel Engine. *Mordovia University Bulletin*, 28(4), 523-536.

Ryblov, M.V., Ukhanov, A.P., Ukhanov, D.A. (2019). Distributed Enrichment of Air Charge of Automotive Engineering Diesel with Liquid Activators. *Volga Region Farmland*, 1(1), 71-77.

Ryblov, M., Ukhanov, A. (2020). Improving of Transport Diesel Engines Energy Efficiency and Environmental Safety by Fumigation of Air Charge. *Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering*, IX, 53-58.

[a]Ukhanov, A.P., Ukhanov, D.A., Rachkin, V.A., Ivanov, V.A. (2009). Biodieselas an Alternative Motor

Fuelfor Tractor Diesel Engines. *Niva Povolzhja*, 2 (11), 71-76.

[b]Ukhanov, A.P., Ukhanov, D.A., Rachkin, V.A., Ivanov, V.A. (2009). Mixer of Engine Fuel Mineral and Vegetable Compositions. *Patent RU2377060.*

Ukhanov, A.P., Shemenyov, D.S., Zelenina O.N. et al. (2010). Comparative analysis of properties of vegetable oils used as biodiesel. *Contribution of young scientists to innovative development of Russian agro-industrial complex. Collection of materials of the All-Russian scientific and practical conference of young scientists*, 125-127.

Ukhanov, D.A., Ukhanov, A.P., Rotanov, E.G., Averyanov, A.S. (2011). Experimental Evaluation Effect of Composite Diesel Fuel for Plunger High Pressure Pump Wearing. *Bulletin Samara State Agricultural Academy*, 3, 105-108.

Ukhanov, A.P., Ukhanov, D.A., Krukov, V.V.et al. (2013). Mixing Filter of Mineral Fuel and Vegetable Oil. *Patent RU2486949.*

[a]Ukhanov, A.P., Ukhanov, D.A., Adgamov, I.F. (2014). Ultrasonic Mixerof Vegetable Oil and Mineral Fuel. *Patent RU 2546891.*

[b]Ukhanov, A.P., Ukhanov, D.A., Adgamov, I.F. (2014). Automotive Diesel Dual Fuel Feed System. *Patent RU2536747.*

Ukhanov, A.P., Ukhanov, D.A., Adgamov, I.F. (2015). The Research Resultsof the Ultrasonic Mixerfor Vegetable-mineral Fuels. *Operation of automotive and tractor equipment: experience, problems, innovations, prospects: Collection of articles of the 2nd International Scientific and practical conference,* 116-120.

Ukhanov, A.P., Ukhanov, D.A., Adgamov, I.F. (2016). Diesel mixed fuel: problems and innovative inventions. *Bulletin Samara State Agricultural Academy*, 2, 46-50.

Ukhanova, Yu.V., Ukhanov, A.P., Ukhanov, D.A. (2017). UltrasonicMixerof DieselCompositeComponents. *Patent RU 2629342.*

[a]Ukhanov, A.P., Ukhanov, D.A., Ukhanova, Yu.V. (2017). Ultrasonic Mixerof Biomineral Fuel Components. *Patent RU2617223.*

[b]Ukhanov, A.P., Ukhanov, D.A., Ukhanova, Yu.V. (2017). Automotive Diesel Dual Fuel Feed System. *Patent RU 2615880.*

Ukhanov, D.A., Ukhanov, A.P., Ryblov, M.V. (2019). Single-point Enrichment of Air Charge of Automotive Engineering Diesel with Liquid Activators. *Volga Region Farmland*, 1(1), 64-70.