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Determining a Rational Composition of Diesel Mixture in Terms of Antiwear Characteristics

Bychenin A.P.
Samara State Agricultural University,
Samara, Russia

Volodko O.S.
Samara State Agricultural University,
Samara, Russia

Ukhanova I.V.
Penza State Agricultural University,
Samara, Russia

Ukhanov A.P.
Penza State Agricultural University,
Samara, Russia

Abstract **– The article provides analysis of main alternative energy resources and considers some variants for substitution of oil motor fuel with renewable resources. A rational composition of diesel mixed fuel (DMF) is justified for mixtures of plant oils (flax oil, soybean oil, crambe) and petrodiesel in the context of antiwear characteristics. Studying frictional characteristics of DMF with a universal tribometer with a four-ball friction unit allowed substantiating limiting and allowable concentration of the biological component, exceeding which leads to adsorption reduction in strength of friction surfaces. For DMFs, the use of flax seed is limited to a range of 20–40 vol %, that of soybean oil is limited to a range of 40–100 vol %; while that of crambe oil is in the range of 60–100 vol %. Despite the effect of adsorption reduction in strength of frictional surfaces at a 60% concentration of crambe oil, when the concentration is higher (up to 100 %) the antiwear characteristics of the crambe oil exceed those of commercial petrodiesel.**

Key wrods – diesel mixture, antiwear characteristics, fuel

I. Introduction

Currently, the problem of saving non-renewable energy resources, in particular petroleum-sourced motor fuels is a pressing challenge. There are many solutions to the problem, however, they all have various drawbacks. For example, replacing traditional internal combustion engines (ICE) with electric motors is limited by small drive range of electric cars. In some countries, there are additional challenges to electrification of motor vehicles in the form of lack or limited amount of electrical resources that may be repurposed to charging electric car batteries and resulting lack or insufficient number of charging stations. Lack of standardization in power grid equipment between countries is also a challenge [1]. Besides, manufacture of electric cars is linked to a rise in prices, as well as problems with operation under severe climatic conditions. The issue of recycling Li-ion batteries utilized in such equipment is also still unresolved [2]. In the future there will be inevitable electrical shortage, as capacities of existing power plants are limited [3].

Some disadvantages of electric cars are eliminated in hybrid cars, which produce electric energy by means of an ICE, serving as a drive for a generator, as well as by recuperating energy while braking. However, the battery recycling issue is still standing, as are most of ICE drawbacks [4].

Using ICE with gas fuel either leads to substituting one non-renewable resource (petroleum) with another (natural gas), or is related to a necessity of having a mature infrastructure for production of alternative gas fuels: special bioreactors (for methane and hydrogen) or industrial gas generators (for syngas) [5]. Besides, switching ICE to gas requires significant changes in its design, as well as in the fuel injectors. Additionally, use of gaseous fuel is linked to increased hazard of combustion and explosion in case of gas equipment malfunction.

The authors hold that currently there are no full-scale substitute for liquid fuels for ICE, however, petroleum is not the only source of such fuel. For example, synthetic gasoline may be produced from coal utilizing a well-known Fischer-Tropsch process. However, it is again substituting one non-renewable resource with another.

The most advantageous sources of liquid motor fuel are biological ones. Plants are used for production of alcohol (sugar cane, corn), plant oils are used as a source for biodiesel production, algae and agricultural plant residues may be utilized as a feed for biogas production. For example, Brazil has been for a long time and quite successfully involved in switching ICE machinery to bioethanol produced from sugar cane [6, 7]. Production of biodiesel (methyl esterified rape seed oil) by means of interesterification process is widespread in Germany [7]. The product is the closest to petroleum diesel by its physical-chemical and operational properties, however, its production requires a mature infrastructure and industrial base in addition to feed sources.

Diesel engines allow using plant oils as fuel without any chemical processing. However, it requires changes to design of fuel injection equipment, as the oils have higher viscosity that prevents their injection into cylinders without treatment, such as heating [8]. Besides, plant oils are characterized with lower cetane number, which impedes their compression ignition. A more promising direction is their use as bio-additives to petroleum (mineral) diesel, producing a mixed plant-mineral fuel. When concentrations of the bio-component is low (under 30 vol %), viscosity of the diesel mixed fuel

(DMF) meets the requirements of GOST 305-2013 and thus may be used in diesel engines without any changes to design of fuel equipment. While use of DMF is associated with a reduction in ICE power (by 3–7 %) and increase in fuel consumption (by 8–12 %), it however, leads to a significant improvement in environmental indicators of the engine. For example, when using up to 50 % of camelina seed oil mixed with petroleum fuel in MTZ-82 + PLN 3-35 during plowing, the working capacity of the D-243 diesel engine reduced by 6.7 %, specific effective fuel consumption increased by 11.3 %, at that, CO content reduced by 12 % [9].

Absolute majority of experimental studies of diesel engines operating on DMF were conducted under positive temperatures, so viscosity of the fuel was taken as the main limiting factor. However, in our opinion, it should be also taken into account that plant oils (from rape, linseed, mustard-seed, camelina, soybean, etc.) contain a lot of surfactants in the form of saturated and non-saturated fatty acids [10], which may exert either positive or negative influence onto the mode of operation of precision joints in fuel injectors. Thus, there is a pressing issue to determine rational compositions of diesel fuel mixes not only by viscosity, but by their antiwear properties as well.

II. MATERIALS AND METHODS

A. *Subject of research*

The subject of research was taken as diesel fuel mix that contains a single plant-derived component in the form of linseed, soybean or crambe oil. Presence of these components leads to increased viscosity of the DMF, which, as noted above, is a limiting factor for applicability of DMF as a motor fuel. However, a concentration of the plant-derived component exceeding the rational value may lead to adsorption reduction of strength [11] in friction surfaces of precision mating couples of diesel fuel equipment. As previous research [10] has shown, oleic acid, a component of plant oils, when used as an antiwear additive may cause this effect at a concentration of 4 vol % or higher. It is logical to assume that this effect may appear when using plant oil as a component in the fuel mix, as the oil is a mixture of saturated and non-saturated fatty acids. In this case, antiwear characteristics will serve as an additional limiting factor to preserve resource of diesel fuel injectors.

B. *Research methods using a universal tribometer*

A universal tribometer with a four-ball friction unit implementing a point contact is suggested as a means to determine antiwear properites of DMF (Figure 1).

In the four-ball friction unit, three lower balls in the race are stationary, while the fourth is being rotated on the shaft of an electric motor. The rotation speed is defined stepwise with a belt drive. The load in the joint is changed with a lever. Friction force at mating, load and temperature of lubricating medium were recorded during the experiment. The temperature was measured with a thermocouple. Results of measurements were output graphically onto a PC screen in real time. The experimental data have been processed using the PowerGraph program, version 3.3 Professional (Fig. 2).

Average wear scar diameter at the bottom balls of the friction unit was taken as a comparison indicator. The measurement is performed at each ball in two orthogonal directions, then the results are summed up and divided by the number of measurements. This value is compared against the reference average wear scar diameter as obtained from testing commercial petrodiesel meeting the requirements of GOST 305-2013. The measurements of the wear scar are carried out with an MBS-1 optical microscope.

Fig. 1. Universal tribometer

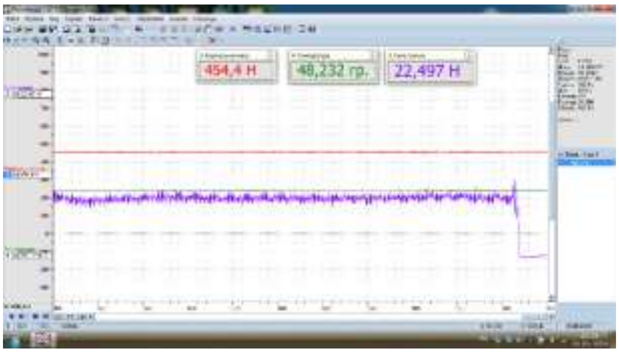

Fig. 2. Screenshot of a working windor of the PowerGraph 3.3 Professional software

C. *Testing method*

DMFs with linseed, soybean or crambe (from *Crambe abyssinica*) oil as a plant-derived component were subjected to testing. The concentration of the plant-derived component in the DMF varied in a range from 0 % to 100 vol % at 20 % intervals. Before each test, the balls were kept in the tested medium for at least one hour. Each experiment was repeated three times. Each experiment lasted for 15 minutes, the tribometer shaft rotated at a speed of 580 min^{-1}, the load was 450±5 N. After the end of the experiment, the friction unit was removed from the tribometer and installed into a special object table in such a way that the plane of the wear scar is perpendicular to the optical axis of the microscope. Average wear scar diameter at the bottom balls of the friction unit was taken as a comparison indicator for antiwear characteristics of oils and DMFs being tested. Then, measurements were performed and statistically treated. The results were used to plot a graph of average wear scar diameter as a function of plant-derived component concentration in the DMF. The experiments were carried out at the same ambient temperature and the same starting temperature of DMF.

III. Research Results

Characteristic curves of average wear scar vs DMF composition are given in Figure 3.

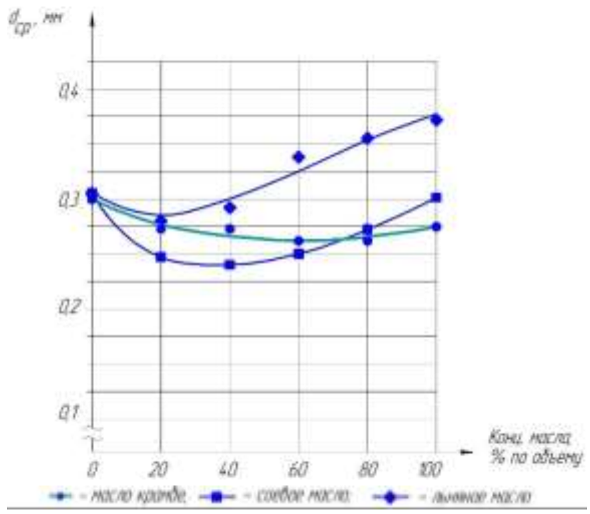

Fig. 3. Average wear scar diameter as a function of plant oil concentration in DMFs

From the characteristic curves shown in Figure 3, it is evident that with increased concentration of the plant-derived component in the DMF, the average wear scar diameter initially decreases, being an evidence of improved antiwear properties of the DMF. Then, when a certain (rational) concentration of the bio-component is exceeded, the diameter starts increasing, indicative of deterioration in the DMF's antiwear properties. This effect may be explained by appearance of adsorption strength reduction in friction surfaces under the action of surfactants in the plant-derived components. As different plant oils differ in their composition, the limiting concentrations for various DMFs differ as well. Analysis of the obtained curves shows that they have extrema in the points with the minimum value of the average wear scar diameter.

For the DMF that contains linseed oil, the optimal concentration from the point of view of the antiwear properties is about 20 vol %. Higher concentrations lead to additional wear of experimental specimens and thus will facilitate increased wear of diesel fuel injectors, as compared with the 20 % concentration of the linseed oil. The linseed oil concentration in DMF may be increased to 40 vol % if the antiwear characteristics of the specimen are to be kept at the level of pure petrodiesel.

For DMFs involving soybean oil and petrodiesel, the limiting concentration of the bio-component is 40 vol %. When it is exceeded, the antiwear properties of the fuel mix deteriorate, however, even when testing the specimens in pure soybean oil (100 vol %), the average wear scar diameter did not exceed that of the reference. Consequently, even without assumed increased resource of fuel injectors, soybean oil may be used as a liquid fuel for diesel engines. However, in this case a change to the design of fuel system is required, e.g., by introduction of additional DMF heater.

For DMFs with crambe oil as a plant-derived component, the limiting contentration of the bio-component is 60 vol %. However, even concentrations up to 100 % will not cause significant deterioration of DMF's antiwear properties, as the average wear scar diameter in the specimen did not exceed that of the reference.

Thus, we may state that use of crambe oil as a bio-component of DMF does not result in significant adsorption strength reduction as compared to DMFs involving soybean or linseed oil. It is explained by differences in fatty acid composition of the oils.

IV. Conclusions

Analysis of experimental characteristic curves shows that for the DMF that contains linseed oil as a biocomponent, the limiting factor for determination of rational composition of the DMF is going to be the allowable biocomponent concentration in the range of 20–40 vol %, that does not cause the adsorption strength reduction in friction surfaces, allowing preserving the resource of fuel injectors. Similarly, for DMFs involving soybean oil and petrodiesel, the limiting concentration of the bio-component is 40–100 vol %. For DMFs that include crambe oil, the range of allowable concentrations is 60–100 vol %, thus, use of pure crambe oil without addition of petrodiesel is predicted to increase the resource of fuel injectors. In the last case, the fuel viscosity is going to be the critical indicator in selection of the rational composition of the DMF.

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