Improvement of Antiwear Properties of Diesel Fuels by Compounding with Additive Based on tall and Linseed Oil

Leonid Stepanovich Keruchenko, Roman Viktorovich Damanskiy

Abstract*: This article discusses possibility to apply additives based on linseed oil aiming at improvement of antiwear properties of diesel fuel. Diesel fuel in engine, together with its main function – production of heat upon combustion, acts as lubricant of precision couplings of engine fuel system. Design peculiarities, specifications and operation conditions of fuel system reveal that diesel fuels do not satisfy the requirements to lubrication of precision couplings of injection nozzles due to poor lubricating and antiwear properties. In order to improve lubricating and antiwear properties of diesel fuels, they are compounded with additives. In Russia imported additives manufactured by various companies are used, not all consumer requirements are met and such additives are very expensive. Compositions and production technologies are not disclosed, though, it is known that such additives are based on plant products (acids of vegetable oils, etc.). Low lubricating properties of Russian fuels, high cost and low efficiency of imported additives require for development of efficient Russian additives aimed at improvement of antiwear properties of diesel fuel and increase in lifetime of engine fuel system. Available information about studies of physicochemical and antiwear properties of composite fuels does not reliably estimate possibility to blend fuel with additives based on vegetable oils. This work is aimed at comparative studies of physicochemical and antiwear properties of commercial diesel fuel and diesel fuel blended with additive based on linseed oil (TLOA) intended for improvement of lifetime of precision couplings of engine fuel systems. The influence of fuel blending with TLOA on fuel antiwear properties (density, kinematic viscosity, surface tension, coefficient of friction, wear) has been estimated. It has been concluded that it is possible to use TLOA to improve lifetime of injection nozzles. It has been revealed that upon diesel fuel blending with TLOA in amount of 5 wt %, the density and viscosity of composite fuel slightly increase but remain in the range of recommendations for summer diesel fuel.

Index Terms*: operation lifetime, injection nozzle, precision coupling, linseed oil, additive.

I. INTRODUCTION

Diesel engines are the main power generating facilities of tractors, harvesters, and other stationary and mobile machinery used in agriculture. Analysis of published data demonstrates that tractor fuel system is the most liable to failures, its share exceeds 20% of overall engine failures. Failures of fuel system result in variations of fuel mixing due to injection pressure drop and cyclic fuel supply. As a consequence, there occur deviations related with timely fuel ignition and combustion resulting in significant loss of engine capacity. The required parameters of fuel injection should be provided by precision couplings of fuel pump and nozzle. These parts are the most unreliable couplings in fuel system of diesel engines [1]. Operation lifetime of injection nozzles of Russian tractor and harvester diesel engines according to State standard GOST 10579–88 (with modifications of 1995-07-01) should be at least 50% of nozzle lifetime, and of automobile diesel engines – at least 3,500 h. Operation lifetime of Bosch injection nozzles is more than 4,500 operating hours [2]. According to various publications, the lifetime of Russian injection nozzles is from 700 to 1,500 operating hours, for instance, in 4ChN15/20,5 diesel engines it does not exceed 1,200 ... 1,300 operating hours, and in 8ChN13/14 engines – 1,500 operating hours, the lifetime of plunger pairs does not exceed 2,000–2,500 operating hours [3-5]. Idle time related with forced replacement of fuel system unit results in significant expenditures. Diesel fuel acts as lubricant of precision couplings, its antiwear properties determine wear and lifetime of fuel system precision couplings. Analysis of operation of diesel engines demonstrates that diesel fuels satisfying the specifications in [6] are characterized by insignificant lubricating capacity which is one of the reasons resulting in very low lifetime of fuel system units, injection nozzles in particular. Recent conversion to EURO diesel fuels related with more stringent sanitary and environmental regulations resulted in removal of main antiwear component contained in diesel fuel: sulfur. This resulted in sharp deterioration of antiwear properties of fuels and lifetime of precision couplings of fuel system. Antiwear properties of fuels could be improved by the so called antiwear additives. At present, due to unavailability of Russian additives, expensive imported additives are used in Russia produced by various companies: Infmeum, BASF, Clariant, Lubrizol and others, which do not completely meet the consumer requirements [2]. Compositions and production technologies are not disclosed, though, it is known that such additives are based on plant products (acids of vegetable oils, tallow oil, etc.). Low lubricating properties of Russian fuels, high cost and low efficiency of imported additives require for development of efficient Russian additives aimed at improvement of antiwear properties of diesel fuel and increase in lifetime of engine fuel system.

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Development and commercial implementation of antiwear additives to diesel fuel at consumption site would permit to increase significantly the lifetime of fuel system units and to solve some other problems occurring upon operation of mobile agricultural machinery [7]. This work is aimed at comparative studies of physicochemical and antiwear properties of commercial diesel fuel and diesel fuel blended with TLOA intended for improvement of lifetime of precision couplings of engine fuel systems.

II. METHODS

The fuel properties effecting evaporation, fuel mixing and combustion, wear are as follows: density, kinematic and dynamic viscosity, surface tension.Physicochemical and antiwear properties of diesel fuel with TLOA were studied in the laboratory of fuels and oils, Chair of agricultural engineering, Omsk State Agrarian University, and in the laboratory of fuels and oils, **"Omskpassazhirtrans" company**, according to appropriate procedures recommended in the standards [4, 5, 8, 9] and specially developed individual testing procedures. The studies were carried out with diesel fuel according to State standard GOST P 52368-2005 (EH 590:2009) as the basis of composite fuel [4]. This choice is based on the fact that the fuel contains minor amount of sulfur and satisfies the requirements of European regulations. This fuel is widely applied in Omsk oblast. Physicochemical analysis is aimed at definition of TLOA content in the fuel which provides operation properties of the composite fuel comparable with those of commercial fuel. The antiwear properties of commercial and composite fuels were determined using four-ball friction machine. The additive was prepared directly prior to use. The additive was based on linseed oil, its properties are summarized in Table 1.

Table 1. Properties of linseed oil used for production of TLOA [10]

Property	Value
Density, ρ, kg/m^3 at 20°C	911
Kinematic viscosity, ν, at 20°C, m^2/s	$15.5 \cdot 10^{-6}$
Ash weight content, %, not more than	0.15
Flashpoint, °C, not more than	240

Antiwear properties during tests at four-ball friction machine are characterized by wear scar. In addition, carrying capacity of fuel was determined by critical TLOAd, and ultimate TLOAding capacity – by welding TLOAd. The tests were performed with balls with the diameter of 12.7 mm made of ShKh-15 steel (bearing 207) according to State standard GOST 3722-81 [11]. A Celestron 40-600 digital microscope was used with magnification of 40–2000× equipped with 0.01 mm scale.Simultaneously lubricating properties of fuels were studied according to HFRR method, which was adopted in Europe for determination of antiwear properties of diesel fuels. This is one of the main methods to determine antiwear and anti-scuff properties of fuels. Fuel properties are determined using two cylindrical gears immersed into considered fuel. The gears under TLOAd are rolled during 15 min under stepwise TLOAd increase while measuring weight loss of the gears. The test is terminated when weight loss achieves 10 mg or after 12 cycles. Lubricating properties of the fuel are expressed in number of passed cycles of TLOAd increase. In addition, ultimate TLOAd is determined at which gears are seized up, it is referred to as OK-TLOAd and measured in Newton (N). Similar method is applied in US: Ryder's test. This method is applied upon estimation of fuels with various level of antiwear properties. Sensitivity of UPS-01 instrument upon estimating fuels with poor antiwear properties is significantly lower than those with good antiwear properties. In this regard the mentioned method was adopted only for estimation of jet engine fuel with good antiwear properties. Similar restrictions are applied for SISST-1 instrument [7].

III. RESULTS

Analysis of the available studies demonstrated that the content of vegetable oil in pure form in diesel fuel should not exceed 5%. Thus, this study devoted to determination of antiwear properties was performed with diesel fuels with TLOA content and physiochemical properties summarized in Table 2.

Table 2. Properties of commercial and composite diesel fuel with TLOA

Properties	Diesel fuel	TLOA weight content, % *				
		0,01	0,02	0,03	0,04	0,05
Density at 20°C, kg/m^3	826	826	827	827	828	828
Kinematic viscosity at 40°C, mm^2/s	3.10	3.30	3.56	3.70	4.0	4.2
Flashpoint in closed crucible, °C	55	55	55	55	55	55
Coking capacity of 10% distillation residue, wt %, not more than	0.3	0.25	0.26	0.27	0.28	0.30
Self-ignition temperature, °C	250	250	250	250	250	250
Cloud point, °C	-25	-25	-24	-24	-22	-21

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Ash content, wt %	0.01	0.01	0.01	0.01	0.01	0.01
Water content, mg/kg	186	187	188	189	190	191
Total impurity content, mg/kg	24	24	24	24	24	24
Corrosion of copper plate (3 h at 50°C), unities	Class 1	Clas s 1	Clas s 1	Clas s 1	Clas s 1	Clas s 1
Oxidation stability: total sediment, g/m^3	25	27	29	29	30	30
Lubricating capacity: adjusted wear scar at 60°C, μm	638	501	387	323	311	306

Fuel number in the table coincides with weight content of linseed oil in the fuel. Density ρ and kinematic viscosity ν of the fuel exert direct impact on antiwear properties of fuel and on injection rate. Fuel density exerts influence on amount of fuel injected into combustion chamber and, as a consequence, the power generated during combustion. Upon operation using fuel with lower density, the cylinder filling with fuel decreases. Upon operation using fuels with increased density, engine efficiency decreases and smoke content of waste gases increases [12]. The density of TLOA at t = 20°C was ρ = 913 kg/m3.

Table 3 summarizes experimental results of antiwear properties of fuels using a MAST-1 friction machine.

Table 3. Wear scar determined at MAST-1 machine

Sample	Wear scar, μm			Wear$_{avg}$, μm	S^2, μm
	1	2	3		
Diesel fuel	651	629	634	638	4
1	492	499	512	501	4
2	386	391	384	387	13
3	319	325	321	323	28
4	309	310	314	311	4
5	301	307	302	306	7
Total					60

Homogeneity of variance of parallel tests (Table 3) was verified by Cochran's Q test. Calculated value of Cochran's Q test was 0.4667. The reference value at α = 0.05, f_1 =2, and f_2 = 6 equaled to 0.7808. Since the calculated Cochran's Q test did not exceed the reference value, the hypothesis of the homogeneity of variance was valid. On the basis of Table 3, mathematical model is obtained reflecting ball wear diameter as a function of TLOA content in the fuel. Experimental results of wear diameter as a function of TLOA weight content are described by the following mathematical model:

$$Wear = \frac{1}{0.000348\alpha + 0.001712}, \qquad (1)$$

where α is the TLOA weight content in diesel fuel.

The model error was verified by Student's t test. The maximum error was 6.33%. Antiwear properties of fuels were estimated also by wear scar and coefficient of electric conductance using the friction machine developed by Chair of agricultural engineering, Omsk State Agrarian University. Figure 1 illustrates the curves characterizing wear scar formed during tests using friction machine as a function of TLOA weight content in diesel fuel.

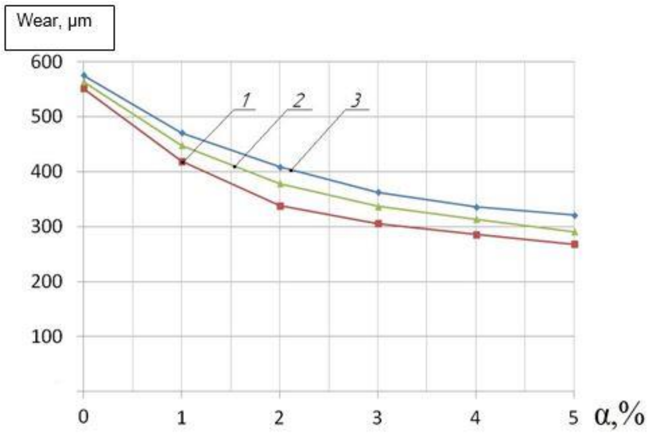

Fig. 1: Wear scar as a function of TLOA content in diesel fuel, TLOAd: 1 - 100 N; 2 - 200 N; 3 - 300 N; experimental value: - P = 100 N; - P = 200 N; - P = 300 N.

Figure 2 illustrates current passing across friction contact as a function of force applied to friction coupling and TLOA weight content in the fuel.

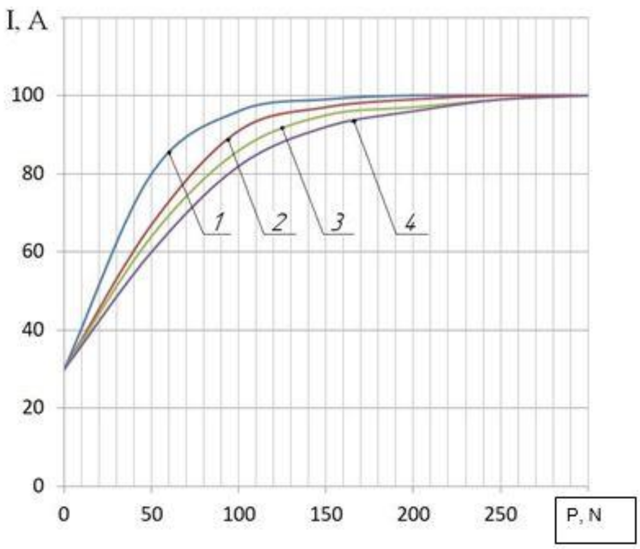

Fig. 2: Current passing across contact as a function of compressive force: 1 - pure diesel fuel; 2 - diesel fuel +0,01% TLOA; 3 - diesel fuel + 0,03% TLOA; 4 - diesel fuel + 0,05% TLOA.

Maximum current was achieved by adjustment and corresponded to direct contact of friction coupling. According to Fig. 2, the best elastic properties are those of fuel with TLOA content of 4–5%.

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Aiming at verification of the assumption that introducing TLOA into diesel fuel provides generation of protecting layer which decreases wear and increases lifetime of plunger pair, the coefficient of friction was measured as a function of TLOA in diesel fuel. Table 4 summarizes experimental coefficients of friction.

Table 4. Experimental coefficient of friction

α,%	0	0,01	0,02	0,03	0,04	0,05
f_{fric}	0.162	0.156	0.151	0.147	0.143	0.141

Variation of coefficient of friction is described by the equation of hyperbolic curve:

$$f_{fric} = \frac{1}{0.1887\alpha + 6.173}, \qquad (2)$$

In Russia, flax is one of the most popular crops. Flax is cultivated for production of fibers and oil. Linseed oil is used as a food product as well as linseed varnish in oil paints [10].

IV. DISCUSSION

Taking into account the aforementioned considerations, it is possible to assume that the injection nozzle lifetime can be improved and required operation conditions can be maintained by reasonable addition from 1 to 5% TLOA to the fuel. Analysis of curves in Fig. 1 reveals that the wear scar on plate surface decreases under any TLOAd with the increase in TLOA content. The wear scar increases with the increase in TLOAd. The curves demonstrate that at P = 200 N, the wear scar does not exceed 460 µm at the additive content in the fuel of 2% and higher. The most efficient TLOA impact is achieved in the content range from 1% to 3%. With the increase in the additive content from 3% to 5%, the wear scar decreases insignificantly, hence, it would be reasonable to use not more than 3% of TLOA in order to improve antiwear properties of diesel fuels. The lowest carrying capacity is that of pure diesel fuel. Direct contact between parts takes place at P = 110–120 N. Diesel fuels with TLOA are characterized by higher TLOAding capacity. Thus, in diesel fuel with 1% of TLOA, the direct contact takes place at P = 140–150 N, with 3% of TLOA – at P = 170–180 N, and with 5% of TLOA – at P = 210–220 N. The increase in diesel fuel TLOAding capacity upon addition of TLOA can be attributed to the fact that unsaturated acids in TLOA form surface layer on surfaces of parts whereas diesel fuel without unsaturated hydrocarbons does not form such layer. Increased elasticity of oil layer decreases wear of nozzle needle and injection nozzle casing.

V. CONCLUSION

Therefore, the experimental results demonstrate that physicochemical properties of composite diesel fuel with TLOA are comparable with those of commercial diesel fuel. Antiwear properties of the composite fuel are twofold superior than that of commercial fuel, its application would improve significantly lifetime of precision couplings of engine fuel system. At the same time, it is possible to mention significant decrease of coefficient of friction and to highlight possibility to use TLOA in fuel in order to decrease wear of engine fuel system.

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