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OPTIMIZATION OF THE COMPOSITION OF BINARY ALTERNATIVE DIESEL FUEL

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Alternative products – rapeseed, sunflower, soy, and other vegetable oils and derivatives – are increasingly being used as diesel fuel. "Biodiesel" fuel – vegetable oil fatty acid methyl esters – have 8-10% higher density and two times higher kinematic viscosity than petroleum diesel fuel. This is reflected in operation in the diesel cylinder and the integral environmental and economic characteristics. The composition of the alternative fuel can be optimized by mixing "biodiesel" with light crude oil cuts. The fractional distillation curves are given for "Biodiesel," gas condensate, diesel fuel (summer and winter), and the proposed binary alternative fuel.

Alternative fuels of plant origin, "Biodiesel," a composite of vegetable oil – rapeseed, soy, peanut, palm, etc. – fatty acid esters, have been increasingly used in Europe and America in the past 20 years [1]. There are approximately ten standards for such fuels in many European countries and the USA.

As an example, Table 1 reports the physicochemical properties of RME (Rapeseed Methyl Ester) fuel according to DIN 51606 (Germany) [1] and DF, petroleum diesel fuels, manufactured in Ukraine according to DSTU 3868 – 99 and in Russia according to GOST 305 – 82 for use in high-rpm diesels and gas-turbine engines in land and marine equipment.

All of the fundamental properties of "Biodiesel" fuel that affect injection, vaporization, carburetion, and combustion in the diesel cylinder are higher than the corresponding characteristics of DF, which is reflected in the operation and integral environmental and economic properties of the engine.

In addition, the physicochemical properties of expanded distillation fuels – GShL and GShZ are also reported in Table 1. The possibility of using them in modern high-speed diesels with direct injection (DI) is examined in [2-4]. It is noted in [4] that "this fuel with all of the required, often contradictory qualities should be composed … of a judicious combination of individual crude oil cuts."

Attention was focused on the need to form ("construct") the optimum composition of fuel with a wide distillation range with consideration of chemical (composition, properties of the fuel), process (parameters, engine design), performance (operating conditions, level of maintenance), and energetic-economic factors, i.e., by application of chemmotological principles [3, 5].

The goal of the present study was to scientifically substantiate the expediency of mixing rapeseed oil methyl esters (ROME) and gas condensate (GC) from Ukrainian fields to create an alternative fuel similar to DF in density, viscosity, and surface tension. These indexes are used in the criteria dependence of A. S. Lyshevskii for approximate calculations of fuel spray characteristics in injection of fuel into the engine cylinder.

In injection of this fuel, the characteristics of development of the fuel spray (rate U_m of the leading edge of the fuel spray, its range l, time τ of reaching the combustion chamber walls, spray cone angle γ) and the fuel spraying characteristics (fuel drop diameter d_{32}, homogeneity of dispersion) correspond to the similar characteristics of DF. As a consequence, the working process in the engine cylinder will not be perturbed by using another kind of fuel.

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TABLE 1

Indexes	Diesel fuel						
	RME according to DIN 51606 (Germany)	according to DSTU 3868–99 (Ukraine)		according to GOST 305–82 (Russia)		GShL according to TU 51-28–86 (Russia)	GShZ according to TU 51-125–86 (Russia)
		S	W	S	W		
Cetane number, min	49	45	45	45	45	40	40
Distillation temperature, °C, min							
50 %	250*	280	280	280	280	260	260
96 %	350**	370	370	360	340	360	340
Viscosity at 20°C, mm^2/sec	6 – 8	3 – 6	1.8 – 6	3 – 6	1.8 – 5	2	1.45
Solid point, °C, max	-4	-10	-25	-10	-35	-15	-25
Flash point*** (closed cup), °C, min	110	62/40	40/35	62/40	40/35	15	12
Sulfur content, wt. %, max	0.01	0.05 – 0.5	0.05 – 0.5	0.5	0.5	0.2	0.2
Iodine number, g I_2 /100 cm^3, max	115	6	6	6	6	–	–
Density at 20°C, kg/m^3, max	875 – 900****	860	840	860	840	860	840

Notes. * Initial boiling point..

** 95% distillation temperature.

*** In numerator: for gas-turbine diesel and marine diesels; in the denominator: for general purpose diesels.

**** at 15°C.

According to the data in [4] and Table 1, the density and viscosity of GC are much lower than for ROME: the cetane numbers of both ingredients are relatively high. The possibility of using fuel compositions with similar density and viscosity to DF was demonstrated in [6, 7]. We imposed additional limitations on the range of ratios of ROME to GC to maximally approximate the performance properties of the binary fuel to DF.

The dependences of standard fuel characteristics – density ρ, kinematic viscosity ν, and flash point (closed-cup) t_{fl}, and nonstandard properties – surface tension σ and dynamic viscosity μ – on the volume ratio of ROME and GC are shown in Fig. 1. The limiting values of these parameters for DF are also shown there. Temperature t_{fl} does not affect processes in the diesel cylinder, but is included in the performance characteristic for safety of rotation with the fuel and the estimated inflammability.

The left boundary of the range of ingredient ratios of (summer) binary fuel is determined by the point of intersection of the curve of the change n in the mixture with the line of the minimum value of ν = 3 mm^2/sec for DF and the right boundary is defined by the points of intersection of the curves of the change in ν and ρ of the mixture with the lines of the maximum values for DF – ν = 6 mm^2/sec and ρ = 860 kg/m^3; the limitations on ρ and ν coincide.

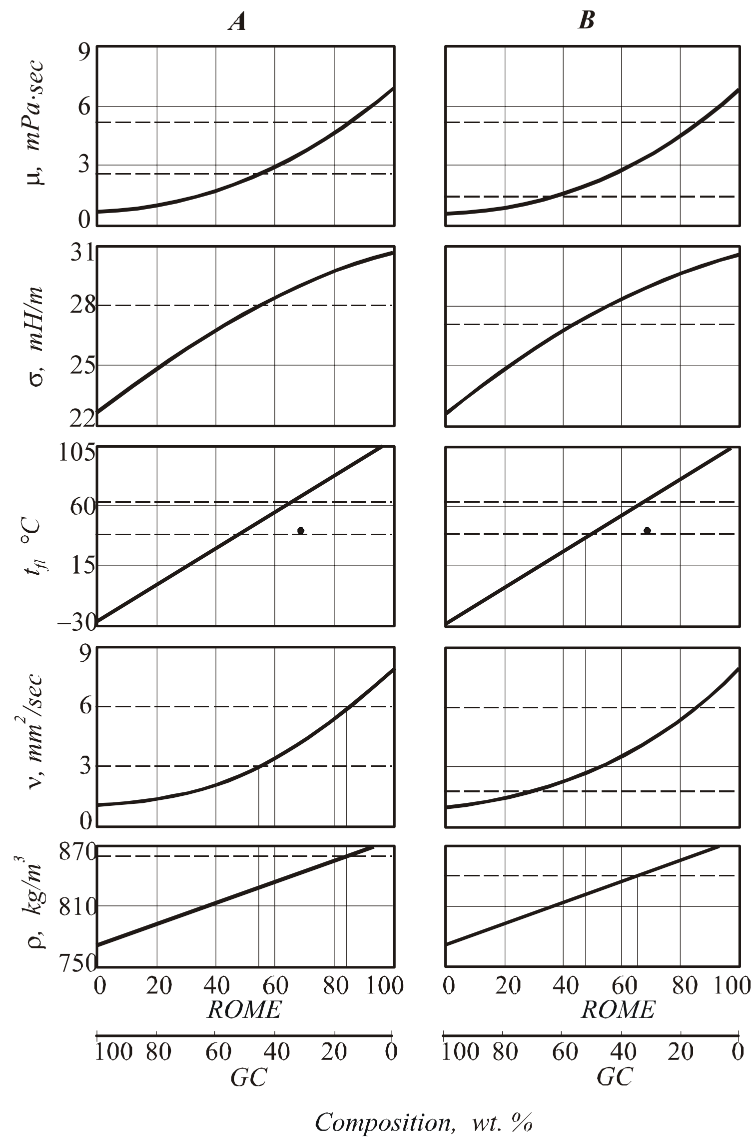

Fig. 1. Characteristics of summer (*A*) and winter (*B*) binary fuels of plant origin vs. their composition: ρ: density at 20°C; ν: kinematic viscosity at 20°C; t_{fl}: flash point; σ: surface tension at 20°C; μ: dynamic viscosity at 20°C; ——: imposed restrictions; •: flash point of 75% ROME + 25% GC determined according to GOST 6356.

The optimum composition of summer binary fuel corresponding to summer DF according to DSTU 3868 – 99 is thus: 55-85 vol. % ROME and 45-15 vol. % GC.

For winter binary fuel similar to winter DF, the left boundary of the ingredient ratio range is defined by the closed-cup flash point (the limiting line of the change in t_{fl} was plotted hypothetically from the condition of additivity of this quantity) and the right boundary was defined by the density of 47-67 vol. % ROME and 55-33 vol. % GC. When GC and ROME with slightly different r and m were used, the binary fuel composition ranges varied slightly.

As indicated above, the restrictions on the optimum composition of the binary fuel with respect to its nonstandard properties are indicated in Fig. 1: dynamic viscosity μ (this quantity, and not ν, is included in the criteria dependences for determination of the values of U_m, l, g, and d_{32}) and surface tension σ. The restrictions on μ are similar to the restrictions on ν, and the restrictions on σ are not maintained.

For summer and winter binary fuels, the values of σ at the end of the optimum composition range are 8-10% higher than the values for DF. With all other conditions being equal, this causes an

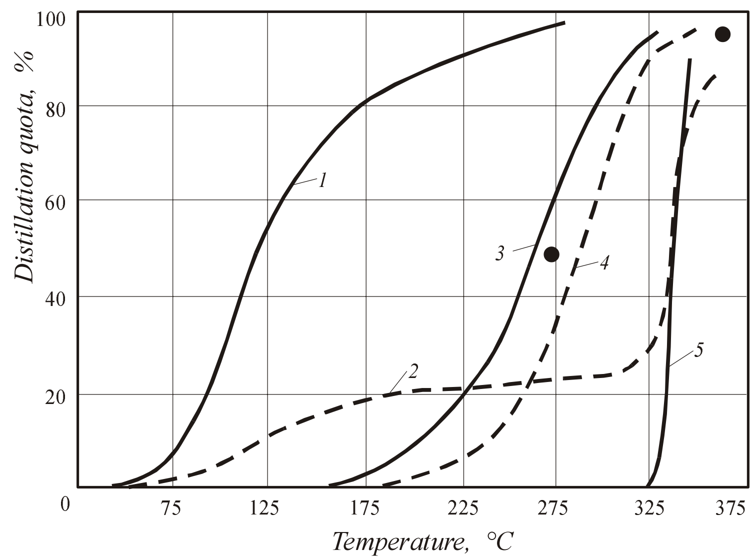

Fig. 2. Fractional distillation curves: 1) gas condensate (GC); 2) 75% ROME + 25% GC; 3, 4) diesel fuel DW and DS [3]; 5) ROME; •: diesel fuel according to DSTU 3868-99.

increase in time τ the fuel spray takes to reach the walls of the combustion chamber by 2.5% and fuel drop diameter d_{32} by 1.3%, while spray cone angle g decreases by 2%. The calculations show that such a change in the properties of the fuel spray are almost not reflected in the effective diesel operating indexes.

The distillation curves of GC (CN = 28) ROME (CN = 51), and 75% ROME – 25% GC (CN = 49) were determined in the petroleum product certification testing laboratory together with colleagues from the laboratory using the method in GOST 2177 – 99 (Fig. 2). The cetane numbers of the fuels were calculated with their density and 10, 50, and 96 vol. % distillation temperatures [8]. Note the unusual shape of the fractional distillation curve of the mixture: 25% GC ($t_{e.p.}$ = 280°C) initially distills, and then ROME distills in a narrow temperature range [9].

Interesting conclusions were drawn in [2] on petroleum fuels. It was noted that with respect to economy of operation and exhaust gas (EG) turbidity of type YaMZ diesel, it is desirable for the 10% distillation temperature of the fuel be equal to 125-150°C if possible, and the 90% distillation temperature to not exceed 300°C.

The first condition is satisfied in the case examined, which suggests satisfactory combustion of the binary alternative fuel in the diesel cylinder in the first phase. The toxicity of diesel EG in operating on the binary fuel will be lower than for standard DF, since in combustion of GC [4] and ROME [1] separately, emission of harmful components is lower. Carbon dioxide emissions will also be lower due to the smaller relative proportion of carbon in ROME [10].

A few words about the characteristics of combustion of pure vegetable oil or binary mixtures with petroleum fuels in diesels. In interpreting R. Diesel's patent on the possibility of burning vegetable oils in a diesel engine, it was noted in [11] that: when oils or mixtures of oils are used, it is necessary to transform the current design of the DI diesel or to use engines with separate IDI combustion chambers.

The analysis [12] of operation DI and IDI diesels on vegetable oils showed that only IDI diesels and in some cases, as an exception, engines with delta-shaped combustion chambers (Central Scientific-Research Diesel Institute type) can operate for a long time on oils and mixtures.

Is it possible to make injection, spraying, and mixing of vegetable oils as similar as possible to these processes with DF? As noted above, this involves mixing the oils with light petroleum fuels (cuts). In [13], sunflower oil was mixed with naphtha (95:5), which reduced the viscosity and density of the binary mixture and slightly improved the fuel economy (by 3.5% in nominal conditions) in comparison to operation on the pure oil. A drawback of naphtha as a component of binary fuel is the low cetane number (10).

In mixing refined rapeseed oil (ν = 88.6 mm^2/sec at 20°C, ρ = 916 kg/m^3 at 20°C) with GC, for example, it is possible to obtain binary fuels with more suitable physical properties for rational organization of diesel operation. The proposed alternative binary fuels based on vegetable oils will also have improved performance characteristics: solid point, cloud point, self-ignition point, etc.

Additional qualification tests are required to confirm these advantages.

Final conclusions concerning the optimum compositions of binary fuels can only be drawn after full-scale tests of 50-85 vol. % ROME and 50-15 vol. % GC fuel compositions in a diesel. When the physical properties of these fuels are maximally close to DF, satisfactory results can be obtained with respect to the effective efficiency. The specific effective composition of the proposed mixtures is approximately 4.5-9% higher than for DF, since ROME is an oxygen-containing compound [10].

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