Using Mustard Oil as Ecological Additive to Petroleum Diesel Fuel

V.A. Markov

Department «Piston Engines»
Bauman Moscow State Technical University
Moscow, Russia
vladimir.markov58@yandex.ru

V.G. Kamaltdinov

Department « Internal Combustion Engines and Electronic
Systems of Cars»
South Ural State University
Chelyabinsk, Russia
vkamaltdinov@yandex.ru

S.S. Loboda

Department «Piston Engines»
Bauman Moscow State Technical University
Moscow, Russia
st-loboda@yandex.ru

Abstract—The relevance of the article is due to the need for wider use of the alternative fuels in internal combustion engines. Advantages of using fuels of vegetable origin as motor fuels are shown. Experimental research of diesel engine D-245.12S functioning on mixtures of diesel fuel and mustard oil of various percentage is given. Possible ways of using mustard oil as fuel for a diesel engine are considered. An opportunity of improving characteristics of exhaust gases toxicity by using these mixtures as a fuel for automobile and tractor diesel engines is demonstrated.

Key words – diesel engine, petroleum diesel fuel, alternative fuel, vegetable oil, rapeseed oil, mustard oil, biofuel mixture

[1] THE FOUNDATION OF MUSTARD OIL USAGE AS AN OXYGEN-CONTAINING ADDITIVE TO PETROLEUM DIESEL FUEL

Among alternative motor fuels, the most attractive fuels are those made of renewable raw sources – biofuel of vegetable origin [1, 2]. As a perspective energy source in motor-and-tractor diesels, the fuel from vegetable oil is considered [3, 4]. This is determined by renewability of its raw, simplicity and ecological compatibility of vegetative oil manufacture, relatively low cost and acceptable inflammability within a diesel combustion chamber (CC). At that, using the mixtures of petroleum diesel fuel with little vegetable oil addition is the most reasonable. So, the diesel operation on the above-mentioned fuels is possible with no significant constructive changes in engines and their systems.

The addition of vegetable oil to diesel fuel noticeably reduces the toxicity of exhaust. Herewith, the possibility to lower the emission of carbon dioxide into atmosphere appears. The emission of critical toxic components includes nitrogen oxides NO_x , carbon monoxide CO , light unburned

hydrocarbons CH_x , soot (also – exhaust capacity). This is determined by a significant content of oxygen atoms in vegetable oil molecules, which amounts to 10-12% in mass. In this case, the vegetable oil is used as an oxygen-containing additive (oxidant).

The oilseeds serve as the source of vegetable oil, wherein different parts – seeds or fruits – contain vegetable fats. At present, European countries primarily use raps for biofuel generation [5-7]. The most significant vegetable oil in Russia is sunflower oil (86.84%). Then soybean oil (7.96%), raps oil (4.84%), mustard oil (0.11%), corn oil (0.04%) and linen oil (0.03%) follow.

The mustard is a plant of cruciferae that include such well-known rural cultures as cabbage, radish, turnip, horseradish, raps, saffron milk cap etc. Mustard oil is obtained from mustard seeds by the compacting method or seed extraction. One should notice that physicochemical properties of mustard oil depend on the sort of oil culture, conditions of breeding and treatment technology.

[2] THE RESEARCH OF DIESEL, RUNNING ON PETROLEUM DIESEL FUEL AND MUSTARD OIL MIXTURES

There are works in evaluation of mustard oil (MO) as a main fuel or as an additive to petroleum diesel fuel (DF) [8, 9, 10]. Alongside, the problem of choosing the optimal MO content as an additive to DF is still unexplored. To evaluate the possibility of using MO as an ecological additive to petroleum diesel fuel and to determine its optimal content, some experimental data of research with diesel engine D-245.12S (4 ChN 11/12,5) of Minsk Motor Plant (MMZ), set on light commercial trucks ZIL-5301, Pavlovsk Motor Plant (PAZ) and tractors «Belarus», are referred to.

Table I. Physically-chemical properties of investigated fuels

Physically-chemical properties	Fuel				
	DF	RO	MO	95% DF+ 5% MO	90% DF+ 10% MO
Density (20 °C), kg/m ³	830.0	916.0	920.0	835.0	839.0
Kinematic viscosity (20 °C), mm ² /s	3.8	75.0	70.0	5.0	7.0
Surface tension ratio (20 °C), mN/m	27.1	33.2	33.1	-	-
Least combustion heating, kJ/kg	42500	37300	37200	42100	41900
Cetane number	45	36	35	-	-
Self-Flammability point, °C	250	318	320	-	-
Clouding point, °C	-25	-9	-8	-	-
Solidification point, °C	-35	-20	-18	-	-
Air quantity for combustion of 1 kg of fuel, kg	14.31	12.50	12.44	14.19	14.11
Content, % in mass					
C	87.0	77.0	77.1	86.5	86.0
H	12.6	12.0	11.8	12.5	12.5
O	0.4	11.0	11.1	1.0	1.5
Common sulfur content, % in mass	0.20	0.002	0.002	0.190	0.180

Table II. The values of diesel engine D-245.12S running on petroleum diesel fuel and its mixtures with mustard oil

Indicators	Fuel		
	DF	95% DF + 5% MO	90% DF + 10% MO
Fuel consumption per hour G_f , kg/h:			
- in maximum capacity mode	20.10	20.17	20.25
- in maximum torque mode	13.00	13.13	13.22
Torque M_e , N·m:			
- in maximum capacity mode	321	321	318
- in maximum torque mode	364	366	363
Fuel specific consumption g_e , g/(kW·h):			
- in maximum capacity mode	248.2	250.1	253.4
- in maximum torque mode	226.2	228.9	231.9
Energy efficiency η_e :			
- in maximum capacity mode	0.341	0.341	0.339
- in maximum torque mode	0.374	0.373	0.370
Exhaust smokiness K_x , % in Hartidge scale:			
- in maximum capacity mode	17	15	12
- in maximum torque mode	42	38	36
Conditional fuel economy values in 13-stage cycle modes:			
- fuel specific consumption $g_{e\text{ con}}$, g/(kW·h)	244.63	247.17	251.08
- energy efficiency $\eta_{e\text{ con}}$	0.346	0.346	0.342
Integral specific mass emissions in 13-stage cycle modes, g/(kW·h):			
- e_{NO_x}	5.911	5.760	5.689
- e_{CO}	2.184	2.140	2.068
- e_{CH_x}	0.675	0.602	0.561

During the experimental research, the exhaust toxicity and fuel economy analysis of diesel, running on DF of «L» type (acc. to GOST 305-82) and DF+MO mixture, was carried out. Some physicochemical properties of investigated fuels are referred in Table 1. In this table, the properties of raps oil, investigated in works 1, 2, are also referred to. The diesel was explored on a motor stand on VSH and at 13-stage (Regulations 49 EEC UN) modes with set pre-injection

$\theta = 13^\circ$ of the crankshaft before TDC and fixed rail position of fuel supply (maximal fuel supply).

At the first stage of research, the test of diesel engine D-245.12C running on pure DF and 90% DF + 10 % MO mixtures at maximal fuel supply was carried out. The results of this test are presented in Fig. 1 and Table 2. At the second stage of research, the diesel was operating at 13-stage cycle ECE R49. The results of these experiments with diesel D-

245.12S are presented in Fig. 2. With a 90 % DF + 10 % MO mixture, using the tendency of NO_x , CO and CH_x , the reduction in the exhaust was observed. The similar test with diesel engine D-245.12S, running on the 95 % DF + 5 % MO mixture, was carried out.

According to the obtained data, the content of toxic components (NO_x , CO, CH_x) in exhaust was determined by common methods, as well as their integral mass emissions in 13-stage cycle ECE R49 (e_{NO_x} , e_{CO} , e_{CH_x} accordingly). At that, the concentration of toxic components (C_{NO_x} , C_{CO} , C_{CH_x}) for each mode was determined and their hourly mass emissions (E_{NO_x} , E_{CO} , E_{CH_x}) were calculated. The obtained values of harmful emissions by each component were summarized for the whole cycle (considering weight coefficients K_i). Then, dividing by conditional mean power for testing cycle $\Sigma(N_{ei} \cdot K_i)$, the specific harmful emissions were determined by [3-5] as:

$$e_{\text{NO}_x} = \frac{\sum_{i=1}^{13} E_{\text{NO}_xi} \cdot K_i}{\sum_{i=1}^{13} N_{ei} \cdot K_i}, \quad e_{\text{CO}} = \frac{\sum_{i=1}^{13} E_{\text{CO}i} \cdot K_i}{\sum_{i=1}^{13} N_{ei} \cdot K_i},$$

$$e_{\text{CH}_x} = \frac{\sum_{i=1}^{13} E_{\text{CH}_xi} \cdot K_i}{\sum_{i=1}^{13} N_{ei} \cdot K_i}.$$

The evaluation of fuel consumption by modes of the 13-stage cycle was carried out by average (conditional) break specific fuel consumption, which was determined by [3-5] as:

$$g_{e \text{ con}} = \frac{\sum_{i=1}^{13} G_{Ti} \cdot K_i}{\sum_{i=1}^{13} N_{ei} \cdot K_i},$$

where G_{Ti} and N_{ei} – hourly fuel consumption and effective power output of engine in i -th mode; K_i – weight coefficient of the mode (the share of mode time). Fuel economy of diesel, running on researched fuels, was estimated by not only break specific fuel consumption g_e , but also by efficiency coefficient η_e .

Fig. 1. Relation of capacity N_e , torque M_e , fuel consumption per hour G_t , air excess ratio α , exhaust smokiness K_x and specific fuel consumption g_e with RPM n of diesel engine D-245.12S for mixtures with different diesel fuel; mustard oil ratios: 1 – 100:0; 2 – 90:10

Besides, to estimate integrally the diesel operation in 13-stage cycle modes, the conditional efficiency coefficient was used, which was determined as:

$$\eta_{e \text{ con}} = \frac{3600}{H_U \cdot g_{e \text{ con}}},$$

where H_U – lower heating value of the fuel, MJ/kg. The results of calculations are referred to in Table 2 and Fig. 3.

Fig 2. Hourly fuel consumption G_t (a), volume concentration of nitrogen oxides in exhaust C_{NOx} (b), carbon monoxide C_{CO} (c) and unburned hydrocarbons C_{CHx} (d) as RPM function of n and torque M_e of diesel engine D-245.12S running on fuels: 1 – DF; 2 – 90% DF + 10% MO

Fig. 3. Hourly fuel consumption G_t , torque M_e and air-fuel ratio α (a), break specific fuel consumption g_e , efficiency coefficient η_e , exhaust smoke opacity K_x (b), specific mass emissions of nitrogen oxides e_{NOx} , carbon monoxide e_{CO} , unburned hydrocarbons e_{CHx} on full-load curve (c) of diesel engine D-245.12S as function of mustard oil content in mixed biofuel C_{MO} : 1 – in maximum capacity mode; 2 – in maximum torque mode.

Data, referred to in Table 2 and Fig. 3, confirm the possibility of improving ecological indicators of diesel D-245.12S with transition from DF to researched mixtures. Such improvement of ecological parameters with DF + MO mixtures was obtained without changes in constructive and regulating parameters of the diesel. To achieve a bigger reduction in toxic components emission and to improve the indicators of diesel fuel economy during adaptation, the construction improvements of the biofuel engine are needed. In particular, it is advantageous to refine the flowing part of nozzles for the reduction of fuel squirt length and to adjust the nozzles with the shape of the combustion chamber, as well as to specify the regulating parameters of diesel (first – to specify the pre-injection and vary it with changes in fuel properties). The other way of improvements in diesel indicators with DF + MO mixtures is optimization of the mixture composition.

[3] CONCLUSION

1. Referred investigations confirmed the efficiency of DF + MO mixtures in domestic diesels and the possibility of enhancing the exhaust toxicity indicators along with mixed biofuel.

2. If running in 13-stage cycle (№49 EEC UN) modes on mixed biofuel 90% DF + 10 MO instead of petroleum diesel fuel, the diesel features reduced emissions of nitrogen oxides e_{NOx} from 5,911 to 5,689 $\text{g}/(\text{kW}\cdot\text{h})$, carbon monoxide e_{CO} –

from 2,184 to 2,068 $\text{g}/(\text{kW}\cdot\text{h})$, unburned hydrocarbons e_{CHx} – from 0,675 to 0,561 $\text{g}/(\text{kW}\cdot\text{h})$.

3. If running on a full-load curve on mixed biofuel 90 % DF + 10 % MO instead of petroleum diesel fuel, the diesel features smoke opacity K_x reduced from 17 to 12% in a maximal power mode ($n=2400 \text{ min}^{-1}$), and from 42 to 36% - in a maximal torque mode ($n=1500 \text{ min}^{-1}$) on Hartridge scale.

References

- [1] A.A. Aleksandrov, I.A. Arkharov, S.N. Devyanin, V.A. Markov, Alternative Fuels for Internal Combustion Engines, LLC Scientific Research Centre Engineer Publ., LLC OnikoM Publ., Moscow, 2012.
- [2] V. L'otko, V.N. Lukanin, A.S. Khachijan, Utilization of Alternative Fuels in Internal Combustion Engines, Publ. of «MADI (TU)», Moscow, 2000.
- [3] V.A. Markov, S.N. Devyanin, V.G. Semenov, V.V. Bagrov, Using Vegetable Oils and Vegetable Oils Based Fuels in Diesel Engines, LLC Scientific Research Centre Engineer, LLC OnikoM Publ., Moscow, 2011.
- [4] V.A. Markov, S.N. Devyanin, S.A. Zykov, S.M. Gajdar, Biofuels for internal combustion engines, LLC Scientific Research Centre Engineer Publ., Moscow, 292 p.
- [5] V.A. Markov, R.M. Bashirov, I.I. Gabitov, Toxicity of Diesel Exhaust Gases, Publ. of Bauman Moscow State University, Moscow, 2002.
- [6] M. Hashimoto, T. Dan, I. Asano, T. Arakawa, Combustion of the Rape-Seed Oil in a Diesel Engine, SAE Technical Paper Series, 2002-01-0867, pp. 1-12, 2002.
- [7] B.M. Spessert, A. Schleicher, Einfluss von Biokraftstoffen auf die Abgas- und Geräuschemission kleiner Industriedieselmotoren, MTZ, №3, 212-221, 2007.
- [8] S.A. Niemi, P.E. Illikanen, V.O.K. Laiho, A Tractor Engine Fueled with Mustard Seed Oil: Optimization, Emissions and Practical Experiences, SAE Technical Paper Series, 972724, 1997, pp. 11-25.

- [9] S.A. Niemi, T. Hatonen, V.O.K. Laiho, Results from a Durability Test of a Mustard Seed Oil Driven Tractor Engine, SAE Technical Paper Series, 982528, pp. 1-15, 1998.
- [10] S.A. Niemi, T.T. Murtonen, M.J. Lauren, V.O.K. Laiho, Exhaust Particulate Emissions of a Mustard Seed Oil Driven Tractor Engine, SAE Technical Paper Series, 2002-01-0866, pp. 1-12, 2002.