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Alternative energy: methanol, ethanol and alcohol esters of rapeseed oil as eco-friendly biofuel

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The authors of the article explain the necessity of using eco-friendly biofuel for motor vehicles. The possibilities and ways of using biofuel in motor vehicles on the basis of alcohols (methanol, ethanol) and methyl ester of rapeseed oil are analyzed. The physical and chemical properties of these biofuel types are presented. In order to develop, determine and optimize the composition of eco-friendly biofuel for motor diesel engines, the authors have tested them during their work in methanol, ethanol-fuel emulsions and methyl ester of rapeseed oil. It has been experimentally established that the use of eco-friendly fuel in transport diesel engines is possible in the form of alcohol-fuel emulsions (alcohol (methanol or ethanol) is 25.0%, detergent-dispersant additive succinimide C-5A is 0.5%, water is 7.0%, diesel fuel is 67.5%) and in the form of separate supply of methanol (88.0%) and methyl ester of rapeseed oil (12.0%).

The experimental research of motor diesel engines working on eco-friendly biofuel types of the above mentioned compositions has been carried out and the perspective decision of improving their environmental performance has been explained. When the diesel engine is operating on a methanol-fuel emulsion, the reduction in the pollutant content in the exhaust gases takes place: nitrogen oxides reduces by 41.3%, carbon soot reduces by 85.5%, carbon dioxide reduces by 6.7%, carbon monoxide reduces by 45.0%. When working on ethanol-fuel emulsion there is a decrease in nitrogen oxides by 50.2%, in carbon soot by 80.7%, in carbon dioxide by 23.8%, in carbon monoxide by 25.0%. And when working on methanol and rapeseed oil methyl ester there is a decrease in nitrogen oxides by 47.4%, in carbon soot by 90.4%, in carbon monoxide by 44.8%.

Keywords: biofuel, methanol, ethanol, emulsion, rapeseed oil, diesel engine.

УДК 631.4

Альтернативная энергетика: метанол, этанол и спиртовые эфиры рапсового масла – экологичное биотопливо

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Обоснована необходимость использования экологичного биотоплива для автотранспортных средств. Проанализированы возможности и пути использования в них биотоплива на основе спиртов (метанола, этанола) и метилового эфира рапсового масла. Представлены физико-химические свойства указанных видов биотоплива. В целях разработки, определения и оптимизации состава экологичных видов биотоплива для автотранспортных дизелей проведены их испытания при работе на метаноло-, этаноло-топливных эмульсиях и метиловом эфире рапсового масла. Экспериментальным путём установлено, что применение экологичного топлива в транспортных дизелях возможно в виде спирто-топливных эмульсий (спирт (метанол или этанол) – 25,0%, моюще-диспергирующая присадка сукцинимид С-5А – 0,5%, вода – 7,0%, дизельное топливо – 67,5%) и в виде раздельной подачи метанола (88,0%) и метилового эфира рапсового масла (12,0%).

Проведены экспериментальные исследования автотранспортных дизелей на экологичных видах биотоплива вышеуказанных составов и обосновано перспективное решение улучшения их экологических показателей. При работе дизеля на метаноло-топливной эмульсии происходит снижение содержания в выхлопных газах оксидов азота на 41,3%, сажи – в 6,9 раза, диоксида углерода – на 6,7%, оксида углерода – на 45,0%; при работе на этаноло-топливной эмульсии – оксидов азота на 50,2%, сажи – в 5,2 раза, диоксида углерода – на 23,8%, оксида углерода – на 25,0%; при работе на метаноле и метиловом эфире рапсового масла оксидов азота – на 47,4%, сажи – в 10,4 раза, оксида углерода – на 44,8%.

Ключевые слова: биотопливо, метанол, этанол, эмульсия, рапсовое масло, дизель.

Nowadays, the constant environmental degradation in the world, especially in large settlements, makes developed countries introduce regulatory restrictions on toxicity and smokiness emissions from vehicles. For example, in Russia, motor transport accounts for 90% of the total amount of harmful substances coming from all kinds of transport. Therefore, the problems of environmental safety of motor transport are an integral part of the country's environmental safety. The significance and severity of this problem is growing every year [1–3].

Each car emits more than 200 different components with the exhaust gases into the atmosphere. At the same time, manufacturers put the environmental compatibility of the exhaust gases into the construction of vehicles at the design stage, and it should not deteriorate while using the vehicles. Therefore, it is not difficult to assume that the future is in the environmentally friendly cars working on alternative petroleum fuels [4–6].

Nowadays the most studied and promising alcohols for using in motor vehicles are monohydric primary alcohols – methanol (CH_3OH) and ethanol (C_2H_5OH). Among the positive methanol properties for its use in motor diesel engines, one can note the presence of oxygen in its molecule, which makes it possible to use methanol as oxygenates (oxygen-containing components), that contribute to reducing harmful emissions of carbon soot and CO in its combustion products [7–10].

The use of these alcohols as an alternative biofuel for motor vehicles became possible as a result of obtaining them in an accessible way from agricultural and food waste, from gaseous fuels. But the more important reason for using methanol and ethanol is to reduce emissions of toxic components in the motor vehicle exhaust gases (Fig. 1) [11].

When using alcohols as fuel for motor diesel engines, the emissions of carbon soot particles and nitrogen oxides can be significantly reduced. Alcohol with its simpler structure and insignificant molecular size is one of the determining factors for a more clean burning of fuel [12, 13].

From all the existing alternative fuels, biofuels and their mixtures with diesel fuel in various proportions (vegetable and mineral mixtures) are promising, and the agricultural enterprises that consume mainly petroleum products as fuel

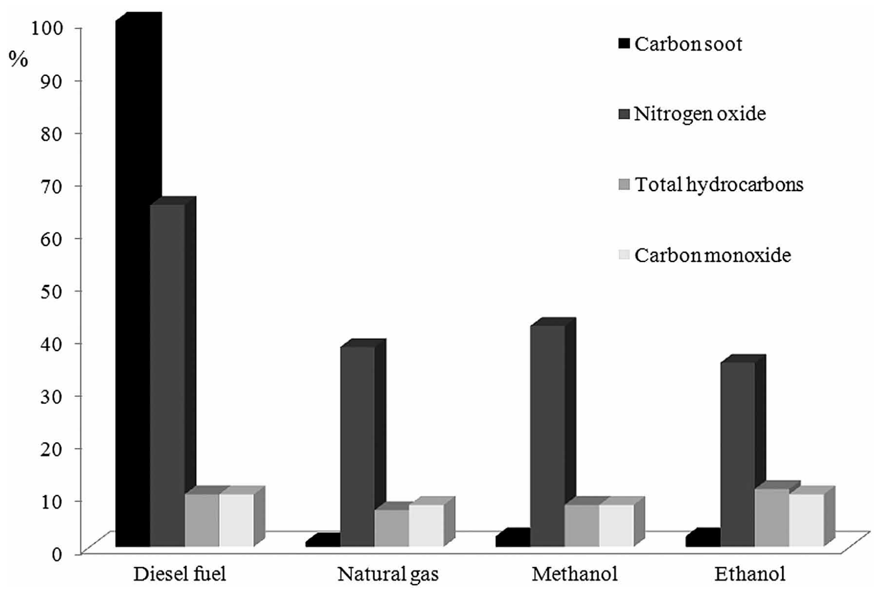


Fig. 1. Relative content of harmful substances in the exhaust gases of motor transport operating on different alternative fuels, % (for 100% diesel fuel on carbon soot is accepted) [11]

Table 1

Physical and chemical characteristics of biofuel and diesel fuel [11]

Indicator	Methanol	Rapeseed oil	Methyl ester of rapeseed oil	Diesel fuel
Density, 20 °C, kg/m^3	795	877	860–900	863
Kinematic viscosity, 20 °C, mm^2/s	0.6	80	12	3.0–6.0
The lower calorific value, MJ/m^3	19.7	36.7	37.2	42.5
Cetane number	3	44	51	45

are now capable of producing eco-friendly renewable biofuel both for urban vehicles and for their machinery [14, 15].

The vegetable oil of any kind is a mixture of triglycerides, i.e. esters, connected to a molecule of glycerin. Glycerin, in turn, also imparts viscosity and density to vegetable oil. Thus, the main task in obtaining biofuel is the removal of glycerin by replacing it with alcohol. At the moment, alternative fuels from rapeseed oil are used in natural form, in the form of methyl and dimethyl ester of rapeseed oil [16, 17].

The methyl ester of rapeseed oil can be characterized by a lower level of coking the motor diesel engines parts than the ethyl ester of rapeseed oil because of its lower viscosity and molecular weight. In addition, methyl esters are better preserved. The advantages of ethyl esters include reduction of smokiness and temperature of exhaust gases and less aggressiveness to engine parts. In the further production process, ethyl esters are less harmful, but in the purification of biofuels to remove excess alcohol there are minor complications, since ethyl alcohol forms the stable aqueous emulsion. In this regard, because of the lower cost of methanol, the production of methyl ester of rapeseed oil is more profitable. Therefore, the methyl ester of rapeseed oil, as an alternative eco-friendly biofuel, is becoming the most popular in Europe [18].

Thus, methanol, ethanol and rapeseed oil are the most suitable for biofuel production, and due to their availability and cost, they can be used as the basis or a component of eco-friendly biofuel for motor vehicles.

The aim of this work is to use eco-friendly biofuels in diesel engines to improve their environmental performance and to save the oil motor fuel.

Objects and methods of research

Compared with other alternative fuels, the cost of methanol is low, and one of its drawbacks is the high heat of evaporation at low boiling point (1104 kJ/kg vs. 250 kJ/kg for regular diesel fuel). This leads to cooling the air charge due to the evaporation of alcohol at low cetane numbers and high self-ignition temperatures, which eventually causes bad ignition in the combustion chamber of the diesel engine. Therefore, the ignition of methanol under such conditions is possible with the help of additionally installed sources of ignition, the supply of methanol at the intake or the use of various catalysts that contribute to reducing the ignition temperature of methanol, and also accelerate the process of combustion reactions. Another effective method of igniting methanol in the combustion chamber of a diesel engine can be the supply of the primer portion of the standard diesel fuel to the combustion chamber. In order to improve the ignition of alcohols, dual fuel-delivery systems are used, which, simultaneously with the supply of alcohol (the main biofuel), make the input of the primer portion of diesel fuel [19].

The required physical and chemical properties of alternative biofuels determine the use of appropriate technologies that can provide operational, economic and environmental indicators. In the production of biofuel, various types of vegetable oils, such as rapeseed, linseed, sunflower, palm oil, etc., are used. At the same time, the biofuel obtained from different vegetable oils has a number of distinctive physical and chemical characteristics. Such characteristics include: the lower calorific value, viscosity, density, filterability, pour point, coking capacity, cetane number, etc. (Table 1) [11].

Thus, the presented data from Table 1 demonstrate the similarity of the biofuel parameters with diesel fuel in terms of density and divergence in kinematic viscosity, lower calorific value and cetane number. Naturally, this fact suggests that it is difficult to apply one type of biofuel in its pure form in diesel engines. Therefore, it has been decided to use biofuel in the form of alcohol-fuel emulsions and methyl ester of rapeseed oil in the combination with methanol, which allows to approximate the values of physical and chemical properties of biofuel to conventional diesel fuel [11, 20].

To conduct the research, at the Department of Heat Engines, Vehicles and Tractors of the Vyatka State Agricultural Academy we have set up the experimental base in the research laboratory of testing motor-vehicle diesel engines. The experimental base includes the electro-brake testing bench SAK-N670 which has a balanced pendulum mechanism, and motor vehicles and the measuring equipment installed on it. The emulsions have been prepared by a homogenizer MPW-302 at a shaft rotation speed of 2000 min^{-1}. The microscopic examination of the emulsions has been carried out with the micrometer MIC-MED 1. Sampling of the exhaust gases has been carried out by the gas samplers of the automatic system of gas analysis (ASGA-T) installed in the diesel exhaust pipeline. The smokiness of the exhaust gases has been measured with the use of a "BOSCH-EFAW-68A" opacimeter. For the input of alternative eco-friendly biofuels, the motor diesel has been equipped with a dual fuel-delivery system. In this case, the ignition of methanol has been carried out by feeding a primer portion of methyl ester of rapeseed oil. This scheme of fuel input completely eliminates the need of using petroleum diesel fuel.

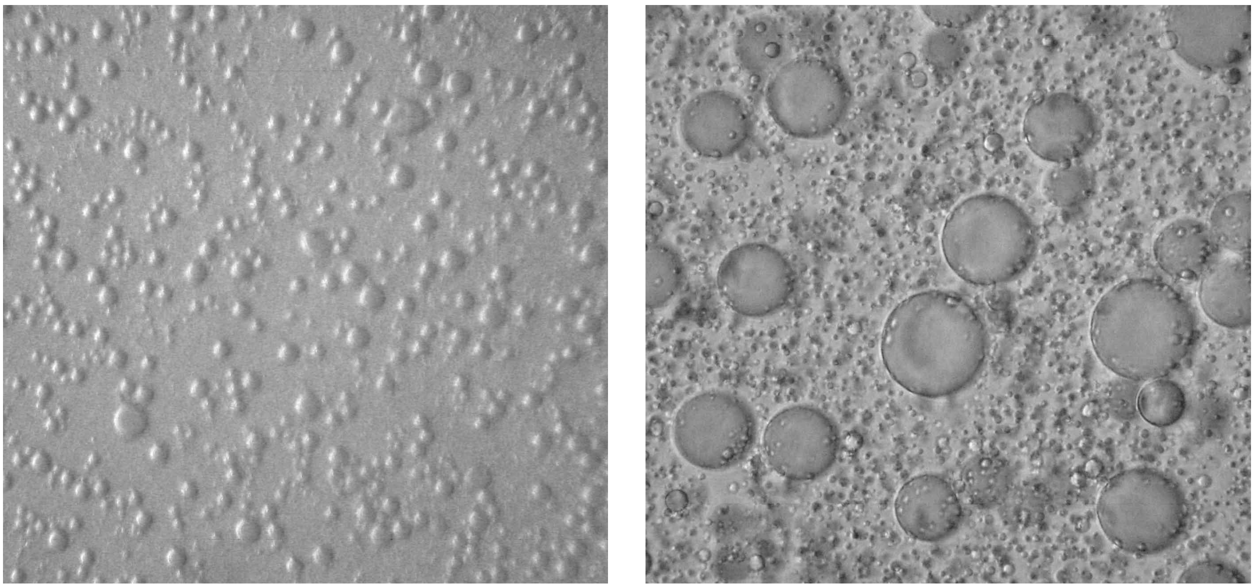
Results and discussion

To determine the composition of alcohol-fuel emulsions, we have performed the microscopic examination of the prepared emulsion samples and the samples with the flocculation process started (Fig. 2).

As you can see (Fig. 2a), the sample has a uniform composition with respect to the particle size, and after some time the particles merge into larger aggregates, which determines the flocculation process (Fig. 2b). Thus, the prepared alcoholic biofuel has a "margin of safety during the time for the sedimentation process (stratification of dispersed systems under the action of gravity with the separation of dispersed phase in the precipitate form), since this does not yet mean the emulsion separation into two phases. During this time, the sample of alcoholic emulsion can take the original composition due to slight shaking (or the engine vibration).

During the tests of the motor diesel engine on alcoholic emulsions, emulsions with the following composition have been used: alcohol (methanol or ethanol) is 25.0%, detergent-dispersant additive succinimide is C-5A – 0.5%, water is 7.0%, diesel fuel is 67.5%. For the motor diesel engine, the eco-friendly biofuel has also been developed, it consisted of methanol (88.0%) and methyl ester of rapeseed oil (12.0%) [11, 20].

Figure 3 shows the dependence on the environmental performance load of the motor diesel engine operating on alcoholic emulsions at the nominal speed mode ($n = 2200\ min^{-1}$). Analyzing the graphs of toxicity and smokiness of the diesel exhaust gases during its work on alcoholic emulsions, it can be seen that the reduction in content of NO_x, carbon soot C and CO_2 takes place throughout the entire range of studies, while the CO content decreases only at the maximum effective load p_e, and C_xH_y increases.



a b

Fig. 2. Microscopic image of ethanol-fuel emulsion in the microscope (the magnification is 100 times): a – immediately after preparation; b – at the beginning of the flocculation process

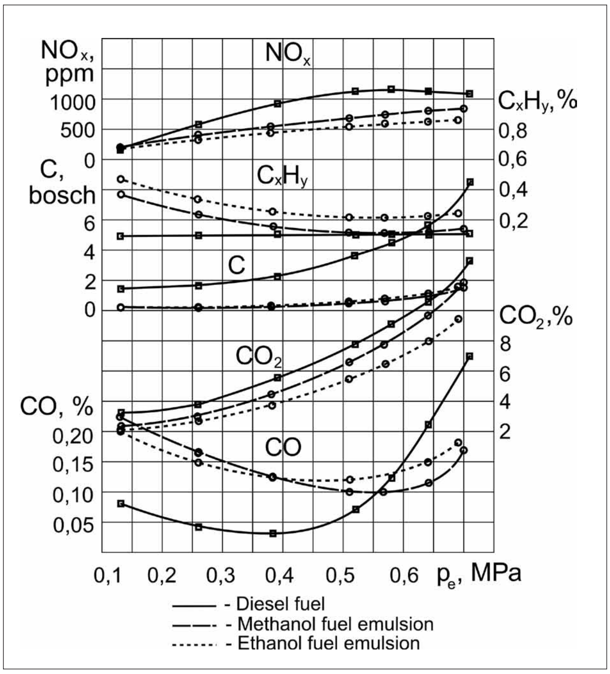


Fig. 3. Changes in the environmental performance of the transport diesel (4F 11.0/12.5) depending on the load change (p_e)

The results of studies of the environmental performance of the motor diesel 4F 11.0/12.5 are presented in Table 2.

So, from table 2 you can see that for the nominal load (p_e = 0.64 MPa) and the nominal crankshaft speed (n = 2200 min^{-1}), the reduction for carbon soot is 85.5 and 80.7% for methanol-fuel emulsion and ethanol-fuel emulsion, respectively.

Figure 4 shows the dependence of the emissions NO_x of the diesel engine operating on methanol and methyl ester of rapeseed oil with a dual fuel-delivery system on various combinations of the adjusting angles of fuel supply timing at nominal operating conditions (n = 1800 min^{-1}, p_e = 0.588 MPa).

As you can see from figure 4, at the optimum adjusting angle of the methanol supply (ΘMet) equal to 34° of crankshaft rotation and at similar combinations of the advance angles of the methyl ester of rapeseed oil, the NO_x values decrease and they are 655, 401, 316 and 243 ppm, respectively.

Conclusion

The authors of the article have given a promising solution for improving the environmental performance of the motor diesel engines, working on the biofuel of the following composition:

1. Methanol-fuel emulsion: methanol is 25.0%, detergent-dispersant additive succinimide C-5A is 0.5%, water is 7.0%, diesel fuel is 67.5%.
2. Ethanol-fuel emulsion: ethanol is 25.0%, detergent-dispersant additive succinimide C-5A is 0.5%, water is 7.0%, diesel fuel is 67.5%.
3. Methanol is 88.0%, methyl ester of rapeseed oil is 12.0%.

When a methanol-fuel emulsion was used as the fuel for the diesel engine, the pollutant content in the exhaust gases has been reduced: nitrogen oxides by 41.3%, carbon soot by 85.5%, carbon dioxide by 6.7%, carbon monoxide by 45.0%. When working on ethanol-fuel emulsion there is a decrease in nitrogen oxides by 50.2%, in carbon soot by 80.7%, in carbon dioxide by 23.8%, in carbon monoxide by 25.0%. When working on methanol and rapeseed oil methyl ester there is a decrease in nitrogen oxides by 47.4%, in carbon soot by 90.4%, in carbon monoxide by 44.8%.

The work of the diesel engine on the alcohol-fuel emulsion helps to save oil motor fuel by 32.5%; and when it works on methanol and rapeseed oil methyl ester, the savings are 100%.

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Table 2

The results of studies of the environmental performance of the motor diesel 4F 11.0/12.5 (n = 2200 min^{-1}, p_e = 0.64 MPa)

Fuel	Indicators			
	NO_x, ppm	C, Bosch	CO_2, %	CO, %
Diesel fuel	1320	6.2	10.5	0.20
Methanol fuel emulsion	775 (decrease by 41.3%)	0.9 (decrease by 85.5%)	9.8 (decrease by 6.7%)	0.11 (decrease by 45.0%)
Ethanol fuel emulsion	657 (decrease by 50.2%)	1.2 (decrease by 80.7%)	8.0 (decrease by 23.8%)	0.15 (decrease by 25.0%)

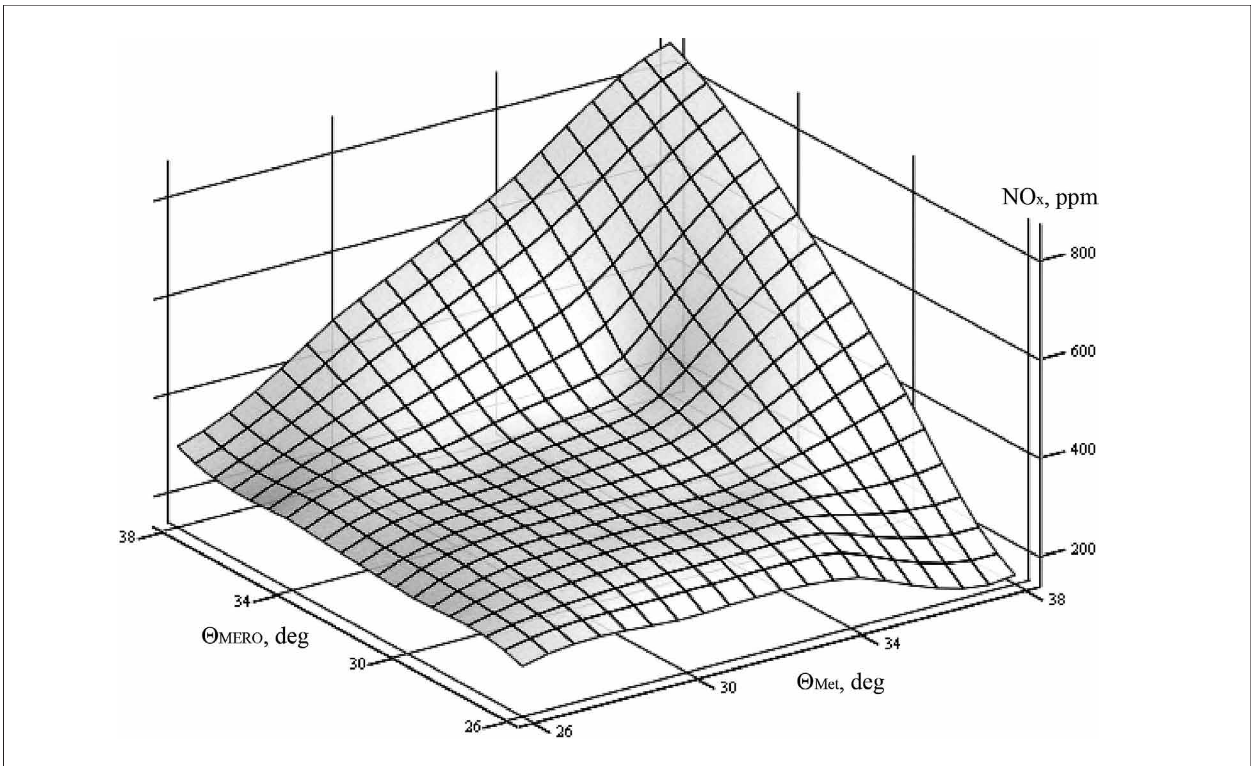

Fig. 4. The dependence of the exhaust gases emissions NO_x of the diesel engine (2F 10.5/12.0) working on methanol and methyl ester of rapeseed oil on the adjusting angles of fuel supply (Θ_{Met} – methanol; Θ_{MERO} – methyl ester of rapeseed oil)

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