Research of high-speed diesel engines of small dimension on biofuel

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Abstract. The paper substantiates the need for the use of biofuels in diesel engines. It is shown that the choice for diesel alternative biofuel with a perspective should be carried out in accordance with the design features of the engine and during its primary tests. The paper studies such eco-friendly energy sources as methanol, ethanol and methyl ether of rapeseed oil. Methanol, ethanol and methyl ester of rapeseed oil potentially lead to some solutions to environmental problems, as for their production, there are quite abundant resources and these energy sources are characterized by relatively low emissions of harmful substances when burning. The ways of bioethanol production from various raw materials and the process of rapeseed oil methanolysis are considered. Experimental studies of biodiesel operating on alcohol-fuel emulsions, methanol and methyl ether of rapeseed oil were carried out.

In recent years, increasing efforts of scientists around the world are aimed at solving the problem of depletion of non-renewable energy resources of the planet. Despite the widespread introduction of energy-saving technologies, the total world energy consumption by mankind is growing. By 2040, the main energy source on the planet will remain exhaustible hydrocarbons (figure 1) [1].

Figure 1. International energy Agency forecast for global energy consumption by 2040.
In order to ensure energy security, the world community is looking for ways to reduce energy dependence on exhaustible fuels. A promising direction for the development of modern energy is the use of biofuel technologies, whose share in the global structure of fuel consumption is steadily growing. One of the main consumers of energy is traditionally the transport industry, which accounts for more than a quarter of total consumption. The share of oil and oil products in the structure of fuel consumption by road in developed countries is up to 95% [2].

In 2001, the European Commission approved a strategy to gradually replace motor fuels with three main alternatives: natural gas, biofuels and hydrogen. In 2009, the European Union Renewable Energy Directive 2009/28/EC was issued, which aims to achieve a 10% share of biofuels used in the transport sector by 2020. In 2003, the European Commission adopted Directive 2003/30EC, which set the goal of increasing the share of biofuels in the total fuel balance for transport from 2% in 2005 to 5.75% in 2010. By 2030, it is planned to replace 25% of traditional fuels with biofuels. According to the international energy Agency, the share of biofuels in the transport sector may increase to 750 million tons in oil equivalent by 2050 and make up 27% of all fuel used by transport [3].

Russia has significant potential in the development of renewable energy sources, including the world's largest area of arable land. The energy strategy of Russia for the period up to 2030 notes the need to ensure a rational, economically justified growth in the use of alternative fuels for transport and energy. The long-term forecast of socio-economic development of Russia for the period up to 2030, approved by the Government, identifies key areas of scientific and technological progress, including the transport system, which plans to develop alternative energy technologies, including the growth of production and use of biofuels in transport. To date, in Russia, biofuels account for no more than 1% of the total primary energy supply, with about a third of biofuels used for electricity generation. In total, transport consumes about 20% of all primary energy, and this share is gradually growing. This accounts for more than 75% of all motor fuel produced. In early 2014, a draft Federal law "on the development of production and consumption of biological fuels" was submitted, which aims to stimulate the processing of biological waste, including for the production of biofuels [4].

The operation of transport is accompanied by significant environmental pollution. The main impact on human health is air pollution by toxic components of exhaust gases, pollution of the water environment, soil and agricultural products. Reducing the share of transport in environmental pollution is one of the main state priorities identified in the Transport strategy of the Russian Federation until 2030. In order to reduce the negative impact of transport on the environment, it is planned to develop and put into operation mechanisms of state regulation that provide motivation for the transfer of vehicles to environmentally friendly fuels. One indicator of achieving this goal is the share of alternative fuels in the total fuel consumption of vehicles, as well as the share of the fleet of mobile vehicles running on alternative fuels. The solution of these tasks involves motivating the transition to the use of environmentally friendly fuels, renewable energy sources, materials and technologies that minimize the negative impact of transport, as well as measures of economic stimulation of environmentally friendly transport technologies, optimization of tariff policy based on the criteria of energy efficiency and environmental impact on the environment [5].

By the decree of the President of the Russian Federation of 07.07.2011 No. 899 "On approving priority areas of science, technology and engineering in the Russian Federation and list of critical technologies of the Russian Federation" is awarded technology based on alternative energy sources as a priority for development. Therefore, it is not difficult to assume that the future of environmentally friendly cars running on biofuels.

The most researched and most promising to date for use in vehicles are Monohydric primary alcohols, such as methanol (CH$_3$OH) and ethanol (C$_2$H$_5$OH). Ethyl alcohol is widely used in the food industry, perfumery, medicine, chemical industry, household needs, leather industry, electronics and,
of course, in the fuel industry. Methyl alcohol has found greater use in the chemical industry and its considerable volumes are used in the production of fuels for motor vehicles.

The use of ethyl and methyl alcohols as an alternative biofuel for vehicles has become possible as a result of obtaining them in an affordable way from agricultural and food waste, from gaseous fuels. But a more important reason for using methyl and ethyl alcohols is to reduce emissions of toxic components with exhaust gases. By using methyl and ethyl alcohols as fuel for diesel engines, emissions of particulate matter and nitrogen oxides can be significantly reduced. This is due to the fact that the combustion of alcohol in the combustion chamber of diesel produces fewer intermediates (in relation to diesel fuel), contributing to the emergence of acetylene and aromatic hydrocarbons, which lead to the formation of soot. In addition, the exhaust gases during the combustion of alcohol is much less different sulfur compounds. Methyl and ethyl alcohols, with their simpler structure and small molecule sizes, are the determinants of cleaner fuel combustion.

Currently, there are enough ways to obtain alcohols as biofuels from various raw materials (biomass, natural gas, coke oven gas, carbon dioxide and others). Ethanol is mainly produced by fermentation from two raw materials, which are starch-based raw materials including corn, grains, barley, grain sorghum, sugar raw materials including fruits, sugar cane, citrus molasses, cane sorghum, sugar beet. In addition, there are ways to produce ethanol from cellulose materials such as wood or paper waste. In addition to these feedstocks, ethanol is produced by hydrating ethylene.

Ethanol can be obtained by direct fermentation of sugars with yeast, from lignocellulose materials and catalytic hydration of ethylene (Figure 2).

![Figure 2. Methods of ethanol production.](image)

The processes required to produce ethanol from various raw materials are shown in Table 1.

| Raw                | Processing                                      |
|--------------------|-------------------------------------------------|
| Tree               | Acid hydrolysis + fermentation                  |
| Tree               | Enzymatic hydrolysis + fermentation              |
| Straw              | Acid hydrolysis + fermentation                  |
| Straw              | Enzymatic hydrolysis + fermentation              |
| Wheat              | Licorice + fermentation                          |
| Candy cane         | Fermentation                                     |
| Sugar beet         | Fermentation                                     |
| A grain of corn    | Fermentation                                     |
| Corn stalk         | Acid hydrolysis + fermentation                  |
| Sweet sorghum      | Fermentation                                     |

Methanol is the simplest alcohol and is known as wood alcohol. Wood alcohols are named because of the method of obtaining by pyrolysis of wood. Currently, methanol is widely used as a commercial chemical. It is directly used and is a raw material for the production of many alcohols, liquid fuels, chemicals and plastics, but is mainly used in the production of other chemicals. Methanol can be derived from renewable and non-renewable fossil fuels including natural gas, coal, biomass, carbon...
dioxide in the atmosphere or from industrial sources such as flue gases emitted by industrial plants from the combustion of fossil fuels. Due to the main source of carbon atoms in its structure - carbon - in addition to these methods, methanol can also be obtained from waste. The efficiency of methanol synthesis from different materials differs, but the most affordable supplier of carbon dioxide for methanol synthesis is natural gas. The efficiency of its synthesis is more than 70% [7].

The biggest difference between diesel fuel and alcohols such as methanol and ethanol is the oxygen level. Diesel fuel has no oxygen atoms, whereas methanol has 10% and ethanol has 50% oxygen content by weight, which makes it possible to use these alcohols as oxygenates (oxygen-containing components), which help reduce the toxicity of exhaust gases.

No less promising today in comparison with alcohols are biofuels and their mixtures with diesel fuel in different proportions (vegetable and mineral mixtures), and agricultural enterprises, consuming mainly petroleum products as fuel, now could provide a solid share of vehicles with raw materials for the production of biofuels. Thus, the calculations show that the energy consumption for obtaining rapeseed is 17700 MJ / kg, for obtaining oil-700 MJ/kg, while the energy obtained from the oil-22200 MJ / kg. Therefore, it can be concluded that the energy profit per hectare of rapeseed will be 3800 MJ (which corresponds to 110 liters of oil diesel fuel for its energy value) [8].

Vegetable oil of any kind is a mixture of triglycerides, i.e. esters, connected to a glycerol molecule. Glycerin, in turn, gives viscosity and density to vegetable oil. Thus, the main task in the production of biofuels is to remove 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 esters of rapeseed oil.

Figure 3 shows the process of rapeseed oil methanolysis. The process of producing rapeseed oil methyl ester from the oil consists in pre-purification of rapeseed oil followed by the addition of methyl alcohol. The catalyst for this reaction is alkali. Then the mixture is heated to 50°C, settled and cooled. The liquid is stratified into two fractions – light and heavy. Light is methyl ether (biofuel), and heavy is glycerin [8].

![Figure 3. The process of methanolysis of rapeseed oil.](image)

Of course, the choice for the diesel engine alternative biofuels with a prospect, whether it is fuel based on alcohol, ether or vegetable oil, or some other new fuel should be carried out in accordance with the design features of the engine and during its initial tests.

In Vyatka state agricultural Academy on the basis of the Department of heat engines, cars and tractors conducted research of working processes of diesel engines running on biofuel.

Figures 4 and 5 show the high-speed toxicity characteristics of biodiesel running on alcohol-fuel emulsions.
Comparing the content of toxic components in diesel exhaust gases when working on diesel fuel and alcohol-fuel emulsions (figures 4 and 5), it can be noted that the use of methanol-fuel emulsion and ethanol-fuel emulsion in diesel leads to a decrease in the content of nitrogen oxides (NOx), carbon monoxide (CO), carbon dioxide (CO2) and carbon black (C) over the entire speed range.

Figure 6 shows the high-speed toxicity characteristics of biodiesel powered by methanol and methyl ether of rapeseed oil.

As can be seen from figure 6, a diesel powered by methyl alcohol and methyl ether of rapeseed oil has a decrease in NOx emissions over the entire investigated speed range. In addition, as the speed increases, the reduction in NOx emissions becomes more significant. Such a decrease in NOx emissions with an increase in speed when working on methanol and methyl ether of rapeseed oil can be explained by an increase in the speed of the crankshaft, resulting in less time for the processes of mixing and combustion, and as we know,
the reduction in the duration of the combustion process is a positive factor inhibiting the formation of nitrogen oxides in the combustion process of fuel in the combustion chamber of diesel.

In General, when working on methanol and methyl ether of rapeseed oil at all speed modes of the engine, there is a significant reduction in emissions from exhaust gases of soot and CO.

Based on the laboratory and bench studies of working processes of diesel engines D-240 (4F 11.0/12.5), D-21A1 (2F 10.5/12.0) the possibility to improve their environmental performance, save diesel fuel by the use of biofuels.

When working on the methanol-fuel emulsion, the content of NO\textsubscript{x} in the exhaust gases decreases from 21.5 to 25.0%, from 37.9% to 2 times, CO\textsubscript{2} from 1.1 to 12.8%, soot from 5.1 to 8.8 times.

When working on ethanol-fuel emulsion, the content of NO\textsubscript{x} in the exhaust gases decreases from 40.8 to 46.0%, from 29.2 to 44.8%, CO\textsubscript{2} from 10.3 to 29.9%, soot from 4.4 to 4.9 times.

When working on methanol and methyl ether of rapeseed oil, the content of soot in the exhaust gases decreases from 7.3 to 12.1 times, CO from 2 times, NO\textsubscript{x} to 46.1%.

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