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Results of the Experimental Research of the Medium Speed Diesel Engine Work on Soybean Oil

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Abstract

The use of alternative fuels derived from oil of plant and animal origin in internal combustion engines gives an opportunity not only to reduce consumer's fuel dependence on the use of petroleum fuels, but also significantly increases the environmental performance of the power plant by reducing toxic components in the exhaust gases. The comparative analysis of the results of the experimental research of the output parameters of the medium speed diesel engine operating according to the load characteristic when using diesel fuel and soybean oil has been performed in the article. The object of the experimental research is a six-cylinder, four-stroke supercharged medium speed diesel engine (26 – the diameter of the cylinder, cm; 34 – the piston stroke, cm) with direct injection of fuel into the cylinder, gas turbine charging and intermediate cooling of boost air. In the process of the research, the technical and economic parameters of the engine and exhaust gas toxicity indicators when working on diesel fuel and soybean oil have been determined. The comparison of obtained indicators has shown that the combustion process when using plant oil is delayed in time and, as a result, the efficiency of the working cycle is reduced. Therefore, there is a need to improve it.
KEY WORDS: *medium speed diesel engine; soybean oil; diesel fuel, maximum pressure; temperature of exhaust gases, emissions of toxic components*

1. Introduction

Internal combustion engines (ICEs) have been and continue to be the main consumers of petroleum fuels. Moreover, diesel engines, due to their greater efficiency compared to petrol engines, and the ability to consume a wider range of liquid fuels, comprise of a higher proportion in installations of various purposes. In modern conditions, when there are processes of price instability due to oil price seasonal fluctuations in the market of petroleum products, the issue of using alternative fuels (liquid fuels of non-petroleum origin) which are not inferior to petroleum fuels in their physicochemical and operational properties, remains relevant. In particular, consumers should have access to renewable raw materials for their extraction and processing, this will give an opportunity to choose the most economical option for obtaining a unit of energy. The main requirements and prospects for the use of vegetable fuels in internal combustion engines have been represented in the article [1].

The advantages of using such fuels are significant, because they provide consumers with ample opportunities for the power plant operation. Examples of such advantages include the ability to independently select raw materials for utilization and processing into fuel, the ability to reproduce raw materials and accumulate their reserves through the use of agriculture and enterprises for processing products and secondary raw materials, the ability to independently form the price per kilowatt of energy, no need for replacement the internal combustion engine power plant for a new, relatively low cost of the fuel system modernization and many others. Separately, it should be noted a significant improvement in the environmental performance of the power plant running on fuels of vegetable origin, although the parameters of economy and efficiency in this case have to be sacrificed.

However, the use of fuels based on vegetable oils in the internal combustion engine has not only advantages, but also contains a number of problems, the main of which is the preparation of this fuel before it is fed into the diesel cylinder. A significant difference in the physicochemical properties of vegetable and petroleum fuels under the same initial conditions (environmental conditions) make it impossible to further start and operate the diesel engine. Therefore, the essential requirement for the use of fuels of vegetable origin is the implementation of a set of measures for fuel preparation, which are aimed to ensure the normal and reliable operation of fuel equipment and diesel engine in general. Failure to fully comply with this requirement entails the violation of the nature of injection, mixing and combustion processes of the fuel-air mixture and with them the reduction of the efficiency of the diesel cycle and related environmental parameters of the internal combustion engine.

The comparative analysis of parameters of the working cycle of the medium-rotating engine received during the experimental research when working on soybean oil and diesel fuel has been carried out in the presented work. The analysis has been performed through the use of the differentiated method, with the help of comparing the corresponding parameters of the engine duty cycle under the same load conditions of the power plant, but when working on different fuels.

The analysis of previous publications and research has shown that the use of soybean oil as a fuel improves engines' fuel-economic and environmental performance [1, 2].

Given the peculiarities of the chemical composition of fuels from vegetable oils, and operational problems that arise when using them, recently more and more attention is paid to the use of fuel mixtures based on a significant proportion of diesel fuel and vegetable oil or its modification, which is proved in such works as [5, 6].

It is obvious that the performance cycle, economy and toxicity depend not only on the physicochemical properties of the fuel, but also on the design, control and operational parameters of the diesel engine, load mode, workflow characteristics, soybean oil composition and level of dispersion during injection.

The process of dispersion of a jet of plant fuel into droplets and blisters has differences in comparison with a similar dispersion of a jet of diesel fuel. Influence on the dispersion process is determined by such indicators as: density, viscosity, surface tension force, fuel elasticity and other physicochemical properties of the fuel. Influencing the process of droplet formation when spraying fuel, the nature of the processes of injection, mixing, heating and evaporation of fuel changes [3, 4, 6], which ultimately affects the combustion of fuel in a diesel engine.

Therefore, taking in consideration the above-mentioned facts, the processes of injection, spraying, mixing and combustion of medium-speed diesel when working on soybean oil and its mixtures of diesel fuel in different percentages have been defined for the research.

2. The Main Principal

The peculiarity of the diesel fuel system of the medium speed diesel engine proposed during the experimental research is that it is flow-type (see Fig. 1) and ensures the operation of the diesel engine on both diesel fuel and vegetable oil. When the diesel engine is running on diesel fuel, the diesel fuel is fed by gravity from the supply tank (*20*) through the fine filter (*9*) to the fuel pumps (*3*). When working on vegetable oil, the fuel is preheated to a temperature of 70 - 75°C in the fuel preparation system before being fed into the diesel fuel system, which consists of a supply tank of vegetable oil (*12*), an electric boiler (*13*), a water pump (*16*), an expansion tank (*17*), a vegetable oil supply pump (*14*) with a pressure reducing valve (*5*), a fuel supply pump to the supply tank (*15*). The fuel in the supply tank (*12*) is heated by water, which is heated in the electric boiler (*13*) and supplied by the circulating water pump (*16*) to the tank coil.

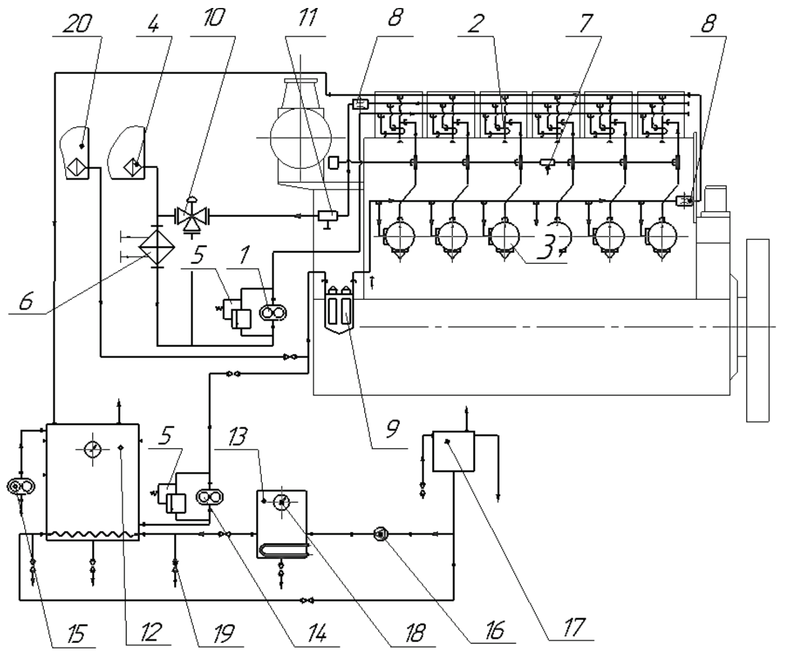


Fig. 1 Schematic diagram of the diesel fuel system when working on vegetable oil: *1* - fuel pump; *2* - cooling nozzle; *3* - high-pressure fuel pump; *4* – strainer; *5* – pressure reducing valve; *6* - fuel cooler; *7* – unload valve; *8* – throttle plate; *9* - fine fuel filter; *10* - temperature controller; *11* – receiver; *12* - supply tank of vegetable oil; *13* - electric boiler; *14* – vegetable oil supply pump; *15* – fuel supply pump to the supply tank; *16* – water pump; *17* – expansion tank; *18* - thermometer; *19* - shut-off valve; *20* - supply tank of diesel fuel

Thermometers (*18*) are installed on the bodies of the supply tank (*12*) and the boiler (*13*) to control the temperature of water and fuel. The mode of operation of the fuel system and fuel preparation system is regulated by shut-off valves (*19*). The fuel that has been heated and filtered in the fuel preparation system is supplied by the pump (*14*) to the engine and through the fine fuel filter (*9*) enters the main fuel network to the high-pressure fuel pumps (*3*) and from the fuel network returns back to the fuel tank (*12*). In accordance with the order of operation of the cylinders, the high-pressure tubes of high-pressure fuel pumps supply a measured amount of fuel to the cooling nozzles (*2*). The amount of fuel and the pressure at which the fuel is fed into the nozzles is determined by the mode of operation of the diesel engine; the excess fuel from the nozzles is collected in the collector of fuel leak and is also sent to the fuel tank.

To maintain the required pressure in the main fuel network, the throttle plate (*8*) with a hole with a diameter of 1 mm is installed on the fuel return pipe in the flow tank.

To protect against increased fuel pressure on the fuel injection pump for cooling the nozzles (*1*), the pressure reducing valve (*5*) is adjusted to the pressure of 0.3 MPa.

Diesel fuel for cooling the nozzles is taken from a separate fuel tank mounted on the exposed face of the diesel engine. After cooling the nozzles, the fuel through the temperature controller (*10*) and the fuel cooler (*6*) enters the inlet of the fuel pump (*1*). The throttle plate (*8*) with a hole with the diameter of 1 mm is installed to create a support at the outlet of the fuel manifold from the nozzles. Diesel fuel for the cooling nozzles circulates in a closed loop.

3. Test Bed and Experimental Results

The experimental research to determine the effective performance of diesel fuel and soybean oil have been carried out on a six-cylinder, four-stroke supercharged medium speed diesel engine (26 – the diameter of the cylinder, cm; 34 – the piston stroke, cm), which is a part of a stationary diesel generator. The specified diesel engine is a four-stroke, liquid-cooled, with an open combustion chamber of the Hesselman type, gas turbine supercharging and intermediate cooling of supercharged air.

Tests of diesel generators (diesel-generator unit - DGU) DGU-900 and DGU-800 (Fig. 2) have been carried out at the enterprise "Pervomaiskdieselmash", according to such parameters as: for DGU-900 nominal power was 900 kW at the crankshaft speed of 750 rpm and use of unrefined soybean oil as fuel; for DGU-800 nominal power was 800 kW at the crankshaft speed of 750 rpm and use of diesel fuel.

The purpose of the first test was to determine the specific fuel consumption during operation of the diesel generator on soybean oil. The parameters of DGU-900 were measured at the modes corresponding to 25, 50, 75 and 100% of the nominal power of the diesel generator. The load was set by active resistances and parallel operation with the electric power system.

For testing on diesel fuel, the load modes of DGU-800 were identical to the output mode of rated power of 800 kW. Thus, the test using diesel fuel was to provide experimental material for further analysis and comparison of the results of two experiments.

Fig. 2 Diesel generator (diesel-generator unit (DGU) - 900) with soybean oil supply system as fuel

Fig. 3 Fuel tank with a soybean oil heating unit

Measurements of soybean oil and diesel fuel consumption were performed by weight. However, the diesel generator for work on soybean oil was equipped with a soybean oil heating unit (Fig. 3). Heated soybean oil was poured into a consumable container, which was installed on the floor electronic scales (VN-300-1 type) with a measuring range of 0-300 kg. On the specified loading modes, the time of consumption by the diesel generator of a portion of fuel weighing 5 kg was fixed.

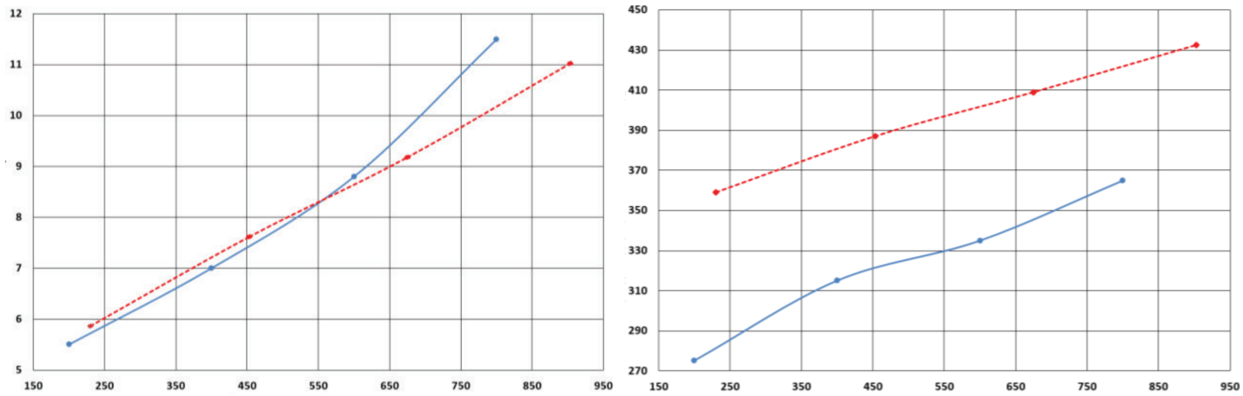
The obtained results of DGU-900 when working on soybean oil and DGU-800 when working on diesel fuel (Table 1) have been presented in Fig. 4 and Fig. 5. In the course of the research, both standard and additional control and measuring devices were used, which were calibrated and meet the current standards.

Table 1

Physicochemical parameters of diesel fuel and soybean oil

The name of indicators	Diesel fuel	Soybean oil
Density at a temperature of 15ºC, kg / m^3	829	920
Lower calorific value of the fuel, kJ / kg	42500	37050
Kinematic viscosity mm^2 / s (at 15ºC)	4,0	57,5
Dynamic viscosity (mPa s) (at 15ºC)	1,32	56,4
Inflammation temperature in ^oC	70	312

Results of the experimental studies. The analysis of the processed test protocols and diagrams (Fig. 4 and Fig. 5) shows that at the power of 800 kW and working on soybean oil, the maximum combustion pressure in absolute terms was 12.7% lower than working on identical load mode, but working on diesel fuel. The specific effective fuel consumption when working on soybean oil and power of 903 kW was 252 g / kWh.



a b

Fig. 4 Load characteristics of the six-cylinder, four-stroke supercharged medium speed diesel engine (26 – the diameter of the cylinder, cm; 34 – the piston stroke, cm) when working on diesel fuel and soybean oil. a – dependence of the maximum pressure (MPa) in the cylinder on loading; b – dependence of the average temperature (°C) of exhaust gases behind the cylinder(s) on loading; - diesel fuel (*P* = 800 kW; *N* = 750 rpm); - soybean oil (*P* = 900 kW; *N* = 750 rpm);

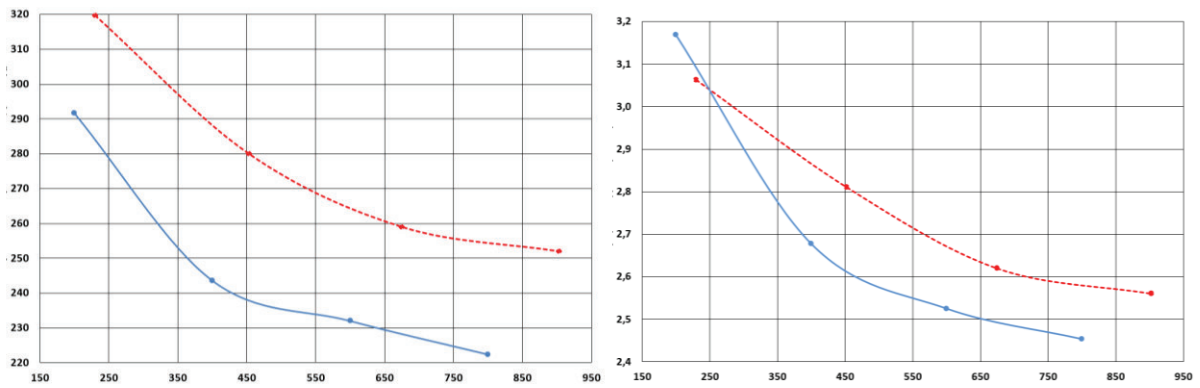


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Fig. 5 Load characteristics of the six-cylinder, four-stroke supercharged medium speed diesel engine (26 – the diameter of the cylinder, cm; 34 – the piston stroke, cm) when working on diesel fuel and soybean oil. a – dependence of specific effective fuel consumption (g / (kW h)) on loading; b – Dependence of the coefficient of excess air on the loading; - diesel fuel (*P* = 800 kW; *N* = 750 rpm); - soybean oil (*P* = 900 kW;
N = 750 rpm)

The temperature of the exhaust gases behind the cylinders when working on soybean oil and the mode of 800 kW is 13% higher than working on diesel fuel, the difference is approximately 60-70ºC. This indicates that the combustion process is delayed in time when working on soybean oil compared to diesel fuel, which has affected the toxicity of exhaust gases. Thus, the concentration of NOx in the entire load range of the diesel engine from 230 to 903 kW when working on soybean oil has ranged from 1276 to 1409 ppm.

The comparative analysis of the results has shown that with lower heat of combustion and worse combustion conditions of soybean oil than diesel fuel, the specific effective fuel consumption is higher by 12.9% for vegetable oil than when working on diesel fuel. Thus, obtaining the power required by consumers needs the increase of the cyclic fuel supply, which will inevitably lead to the increase in the maximum injection pressure, which is not desirable from the point of view of reliable operation of the internal combustion engine.

The difference in fuel density, where soybean oil is 9% higher than diesel fuel, will affect the injection parameters. First of all, this factor applies to increasing the range of the fuel jet of flame and reducing the cone of its disintegration. The difference in viscosity and surface tension force for soybean oil and diesel fuel will increase the number of droplets of large diameter when disintegrating, and in accordance with the delay of their heating and evaporation, and at the same time combustion.

The coefficient of excess air when working on soybean oil (800 kW mode) is 5% higher than when working on diesel fuel, which is the result of the need for better air supply of the combustion process when using vegetable oil as fuel.

Thus, the results of the experimental research allowed to compare the efficiency of soybean oil and diesel fuel under identical conditions of diesel engine loading and to draw conclusions about the prospects for the use of fuels from vegetable oils in the medium-rotating engine.

4. Conclusions

The conducted experimental research of the medium-rotating engine gave an opportunity to determine the parameters of the working cycle, economy and environmental safety when using fuel from soybean oil.

The use of soybean oil in the medium-rotating engine with the smaller value of lower heat of combustion than in diesel fuel leads to the increase in the specific effective fuel consumption by 13%.

Physicochemical properties of soybean oil affect the processes of injection and mixing, and as a result, the combustion process is delayed. The study of the processes of disintegrating a jet of fuel from soybean oil should be included in the further experimental research.

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