Journal of Engineering and Applied Sciences 15 (3): 789-794, 2020
ISSN: 1816-949X

The Heating System of a Diesel Engine and Diesel Generator

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Abstract: The proposed development relates to heat power engineering and can be used in energy, petrochemical and food engineering. It can be used in the engine industry and in particular in lubrication, cooling and fuel supply systems of Internal Combustion Engines (ICE) in the regulation and maintenance of optimal temperature conditions. The aim of the study is to develop and study the system of heating biodiesel used in diesel generator sets in order to ensure its high technical and economic performance. The study presents a mathematical model of the working processes of the engine running on different types of fuel. The method of experimental studies on the study of thermophysical parameters of fuels and to assess their impact on the efficiency of the internal combustion engine in the course of motor tests. The results of laboratory studies of thermal and physical parameters of fuels and obtaining quantitative dependences describing the change of these parameters on temperature are carried out and described; the results of motor tests of diesel generator sets under load characteristics to study the effect of different fuels and fuel temperatures on the effective performance of diesel; as well as research and development of the design of the fuel heater with a changing surface area of heating. The economic efficiency of application of biofuels and fuel heater in the diesel generator set is proved.

Key words: Diesel generator, diesel, diesel fuel, biodiesel, binary fuel, mathematical modeling, fuel supply, workflow, fuel heating, heat exchanger, thermal performance, physical and chemical properties, load characteristics, annual savings, payback period

INTRODUCTION

At present, issues related to the development of heat power occupy an important place all over the world. Most countries of the world in an effort to reduce the severity of heat power issues are actively carrying out activities to introduce alternative energy sources, measures in the field of energy technologies as well as small energy. In other words, issues of power system more and more autonomous switching to alternative heating. This reduces costs and makes much more efficient use of energy resources. Today in the world there is an understanding that the depletion of the Earth's interior is becoming more urgent every day (Gonzalez-Delgado *et al*., 2017).

Today's most common sources of energy are natural resources. Reducing the consumption of natural resources in thermal power plants today for many countries of the world to become the main task and for science and scientists to study new opportunities to create "new energy" for the needs of people. Today it is one of the important concerns related to the environment and efficient use of energy resources (Khuenpetch *et al*., 2017).

Active application in modern heat power engineering, the diesel generator sets working on biofuel allows to solve easily the whole complex of the above-mentioned problems, namely to provide:

- Decentralized electricity and heat supply to the population and production
- Automation and informatization of electricity and heat supply systems
- Use of energy-saving energy carrier with high fuel efficiency due to increased heat utilization
- Improvement of environmental performance through a more complete process of combustion and processing of plant and animal waste

All these factors give reason to consider the topic of this study relevant.

MATERIALS AND METHODS

In this study, theoretical and experimental studies are carried out, mathematical modeling of diesel operating processes on various fuels is carried out, experimental studies of thermophysical parameters of biodiesel and their comparison with the parameters of mineral diesel fuel are carried out, load characteristics are obtained, the design of the biodiesel heater is developed and its parameters are justified.

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In the course of research were used methods of mathematical modeling, mathematical statistics, theoretical principles of engine working processes, heating engineering, the methods used to study the performance materials and graphic presentation of research results, etc.

RESULTS AND DISCUSSION

As a result of the analysis of the state of the issue found that the reduction of oil, gas, coal and other energy resources in the world raises the problem of energy conservation. The solution to this problem is largely associated with the development of alternative energy which uses solar, wind, geothermal, biological energy as energy resources (Khuenpetch *et al*., 2017; Senthur *et al*., 2014).

For the Russian Federation which has a huge territory located in the zone of temperate, subarctic and Arctic latitudes, small energy using biofuels as an energy source becomes particularly relevant. The concept of small energy is the use of diesel generators of low power as installations for generating electricity and heat. At the same time, the efficiency of such power plants has a value of 80-90% which makes it very effective. However, the lack of liquid and gaseous mineral fuels requires the use of biodiesel as a fuel (Khuenpetch *et al*., 2017; Manurung *et al*., 2017).

Biofuel in its pure form, at this point in time, the chemical industry has not developed. Improving its properties additives is a mixture consisting of 75-80% of mineral diesel fuel and 20-25% biodiesel based on various vegetable or animal fats (oils) as well as products of their esterification (esterification-the reaction of the formation of esters in the interaction of acids and alcohols). Physical and chemical parameters of biodiesel, namely, density, viscosity, flash point and a number of other indicators (for example, hydrocarbon composition) are much worse than mineral diesel fuels. This reduces the starting properties of the biodiesel affects the process of combustion and heat dissipation (Manurung *et al*., 2017).

The solution of the issue of improving the performance properties of biodiesel and improving its starting qualities, as well as combustion performance is possible through the development of special additives or improving the power system, specifically, the development of fuel heating devices. The analysis of patent solutions and design devices of fuel heating shows that the most effective way to solve this problem is the use of electric heaters in fuel purification filters or the use of electronic microprocessor systems to regulate heating modes (Durairaj *et al*., 2016).

Despite the high efficiency of electric fuel heating systems, they have low reliability and depend on a constant power supply. Diesel generators running on biofuel in temperate latitudes and the far North should be more Autonomous and for this it is necessary to develop a heating device that would be able to heat the fuel without the use of electric energy, i.e., from the engine itself (Thanigaivelan *et al*., 2017).

As a result of the comparative analysis it is established that the use of biodiesel, despite the deterioration of a number of thermodynamic parameters of the cycle, gives comparable results with diesel fuel on the effective and indicator indicators. This is due to the increase in useful work resulting from the redistribution of the amount of energy produced by the combustion of biodiesel.

In order to determine ways to improve the performance of biofuels, a simulation of diesel on binary fuel B-20 was made. As a result of modeling it is established that the obtained in-cylinder parameters do not differ from each other. Moreover, it was improved environmental performance as well as indicator and mechanical efficiency which allowed the diesel to maintain its fuel efficiency.

Also we performed a simulation of the operation of the feed system of a diesel engine and the influence of physico-chemical parameters of fuels and fuel temperature on the performance of the fuel supply. In the course of modeling, minor indicators of improving the fuel supply of biodiesel were obtained which indicates that the heating of the fuel does not affect the hydrodynamics of injection but leads to the activation of fuel combustion processes and contributes to the processes of redistribution of energy between the heat supplied to the fuel cycle to the value obtained during its combustion of useful work (L'otko *et al*., 2000).

Analysis of the working process of the engine running on biofuel showed that at low temperature and low loads, vegetable fuel ignites poorly and conversely at high temperatures and high load, vegetable fuel ignites well enough (Nigmatulin, 1987).

The calculation and theoretical substantiation of the parameters of the heat exchanger for heating fuel is performed. In the course of theoretical analysis, the parameters of the fuel heater are justified. The power of this heater is 25-30 J kg^{-1} of heated fuel.

The temperature of the fuel during heating should be between 20 and 60°C. It is better to combine the fuel heater with the fuel fine filter or install it after the filter at the inlet to the fuel high-pressure pump.

To heat the fuel, the heat exchanger must be able to heat it in the range of 0.5-2.5 kg h^{-1}. If we accept that the heat capacity of B-20 does not change with temperature, then the heat output of the heat exchanger should be (Salmin and Fedotov, 2015; Salmin and Zhuk, 2016):

$$Q_H = C_{pi} \times (G_T/3600) \times \Delta T, \text{ kW} \quad (1)$$

In Eq. 1, the heat Capacity of C_{pi} is a temperature dependence which can be represented as an equation:

$$C_{pi} = Cp_0 + \Delta_C \times (T_i - 273) \quad (2)$$

Where:

- Cp_0 : The heat capacity of the fuel at 0°C, kJ/(kg×K)
- T_i : Design temperature at which the true heat capacity is determined K
- Δ_C : Constant increase of heat capacity from temperature, kJ/(kg×K^2)

The value is determined experimentally. The temperature change can be determined based on the temperature difference between T_0 = 288 K and the current heating temperature by the equation $\Delta T = T_i - T_0$ or based on the equality of the densities of diesel fuel and binary fuel B-20:

$$\Delta T = [(\rho_{(DF)0} + \Delta_\rho \times 38.2 - \rho_{(B-20)0} - \Delta_{\rho i} \times 273)/\Delta_{\rho i}] - 288 \quad (3)$$

Knowing the equation for determining the Q_H and the value of the temperature difference ΔT when heating the fuel in the heat exchanger, as well as using the known heat transfer equation to determine the value of the heat flow transmitted by the heat exchanger, we determine the surface area of the heat exchange:

$$F = \frac{Q_H}{k \times \Delta T} \quad (4)$$

where, k is heat transfer coefficient of the heat exchanger, W/(m^2×K). Assuming that the temperature differences in Eq. 3 and 4 are numerically equal, we obtain an expression for determining the heating area of the heat exchanger:

$$F \approx \frac{1000 \times C_{Pi} \times G_T}{3600\left(\frac{1}{\alpha_T} + \frac{\delta}{\lambda_M} + \frac{1}{\alpha_\Gamma}\right)} = \frac{0.278 \times G_T \times \left(C_{P0} + \Delta_C \times \left(T_i - 273\right)\right)}{\frac{d_T}{Nu_T \times \lambda_T} + \frac{\delta}{\lambda_M} + \frac{h}{Nu_\Gamma \times \lambda_\Gamma}} \quad (5)$$

Where:

- d_T : The diameter of the fuel line (m)
- δ : The wall thickness of the fuel line (m)
- h : Height of the fuel line washed by exhaust gases in the heat exchanger (m)
- λ_M : Thermal conductivity of the fuel line material (W/(m×K))
- λ_T : Fuel thermal conductivity (W/(m×K))
- λ_Γ : Thermal conductivity of exhaust gases (W/(m×K))
- Nu_T : Nusselt number for fuel
- Nu_Γ : Nusselt number for exhaust gases

The heat exchange area of the device is determined by the equation:

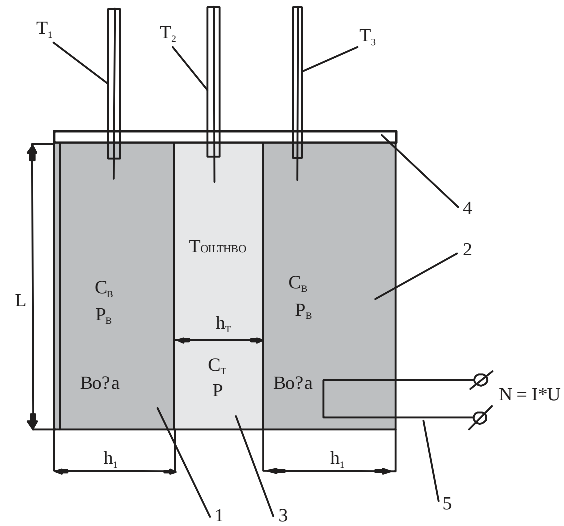

Fig. 1: Installation for determination of heat capacity and thermal conductivity of fuel (1) Water tank, (2) Water tank, (3) Fuel tank, (4) Wooden tank cover and (5) Electric heater

$$F = \pi \times d_T \times h, \ m^2 \quad (6)$$

Since, the diameter of the fuel line in the engine design does not change then to calculate the heat exchanger, the desired parameter of the heat exchanger is the height or length of the fuel line which will be equal to:

$$h = \frac{0.278 \times G_T \times \left(C_{P0} + \Delta_C \times \left(T_i - 273\right)\right)}{\pi \times d_T \times \left\{\frac{d_T}{Nu_T \times \lambda_T} + \frac{\delta}{\lambda_M} + \frac{h}{Nu_\Gamma \times \lambda_\Gamma}\right\}} \quad (7)$$

Calculations also showed that the value of the heat transfer coefficient of the fuel heater is 22-27 W/(m^2×K). In the course of laboratory studies, the density of diesel fuel was determined by the requirements of GOST R ISO 3675-2007 and the kinematic viscosity according to GOST R 53708-2009. A pilot plant was developed to determine the heat capacity and thermal conductivity Fig. 1.

Laboratory installation for definition of the heat capacity and the thermal conductivity of the fuel was a container of cubic shape, divided into three parts (1) Water tank, (2) Water tank, (3) Fuel container, (4) Wood cover of the tank (5) Heater. In all three compartments through the lid mounted alcohol thermometers brand TTZH-M with a scale from 0-150°C and the price of division 1 C. Water heating is carried out using electric heater brand 32A13/1,0-P-220V f.2 R30 1 kW with connection to the mains supply with variable voltage from 220 V. Connection of the electric heater is carried out through the laboratory adjustable auto transformer

Table 1: Temperature dependences of thermophysical parameters of fuels

Type of fuel	ρ (kg L^{-1})	λ, W/(m×K)	υ, (mm^2 sec^{-1})	Cp, kJ/(kg×K)
DF	ρ = 0.838-0.00063×(T-273)	λ = 0.1187-0.000116×(T-273)	$υ = 8,18×T^{-1,133}$	Cp = 1.88+0.00577×(T-273)
BD	ρ = 0.896-0.00067×(T-273)	λ = 0.1199-0.000117×(T-273)	$υ = 13,36×T^{-1,133}$	Cp = 1.934+0.0059×(T-273)
B-20	ρ = 0.0849-0.00064×(T-273)	λ = 0.1189-0.000116×(T-273)	$υ = 6,74.4×T^{-1,133}$	Cp = 1.891+0.0058×(T-273)

LTC-4.Measurement of the time of water heating is carried out stopwatch brand Soppr-2A-3-000. The tank is made of steel sheet with a thickness of 1 mm. The dimensions of the tanks: h1 = 80 mm, h_T = 20 mm, height L = 200 mm, width of the tank A = 200 mm, Volume of the water compartment V = 0.0032 m^3, V_T = 0.0008 m^3.

Determination of the coefficient of thermal conductivity in the laboratory installation was carried out according to the equation:

$$\lambda_T = h_T \times \left[\frac{I \times U}{A \times L \times (T_1 - T_3)} - 2 \times \left(\frac{\lambda_{CT}}{\delta_{CT}} \right) \right], \ W/(m \times K) \quad (8)$$

A heat capacity according to the equation:

$$C_T = \frac{I \times U \times \tau \times 10^{-3} - C_B \times \rho_B \times V \times (T_3 - 2 \times T_o - T_1)}{\rho_T \times V_T \times (T_2 - T_0)}, \ kJ/(kg \times K) \quad (9)$$

Or

$$C_T = \frac{I \times U \times \tau \times 10^{-3} - 13.408 \times (T_3 - 2 \times T_o - T_1)}{0.0008 \times \rho_T \times (T_2 - T_0)}, \ kJ/(kg \times K) \quad (10)$$

In the course of laboratory tests of Diesel Fuel (DF), Biodiesel (BD) and Binary fuel B-20 were obtained physico-chemical and thermophysical parameters of fuels depending on temperature (Table 1).

During the motor tests carried out under the conditions of load characteristics, it was found that the use of fuel heating in the diesel power supply system has a small technical and economic effect within 3-6%. The use of a fuel heater in the power supply system of a biodiesel-powered diesel is justified by additional fuel savings in the range of 4-6% and in order to improve the starting qualities of biodiesel. The results of the study are shown in Fig. 2.

The results of the diesel engine tests on binary fuel B-20 showed that the use of such fuel is more appropriate than equipping the engine with a fuel heating system, since, its fuel efficiency indicators practically correspond to the diesel parameters when operating on diesel fuel.

In addition, the results of experimental studies in the operation of diesel on different types of fuel in general confirmed the results of mathematical modeling and showed that the method of thermal calculation of ice, developed in 1907 by Grinevetsky (1907) outdated and requires revision, since, the calculation of the processes occurring inside the cylinder of the engine practically

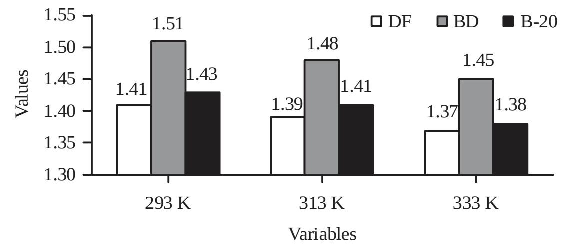

Fig. 2: Change in the average hourly fuel consumption of diesel TMZ-450D when it is running on different fuels and with different fuel temperatures

does not take into account such thermophysical parameters as density, coefficient of thermal conductivity, activation energy and other indicators which affects the accuracy of calculations during the combustion of fuel and its heat dissipation.

In this study, the design of the fuel heater with self-regulation of the fuel heating surface area is proposed. In addition, a comparative technical and economic analysis of the payback of the diesel generator set with the used biofuel heater is given. The expediency of the use of biodiesel in low heat.

The design of the fuel heater is shown in Fig. 3. The proposed technical solution has a high technical and economic efficiency and can serve as the basis for the development of a model range of heating devices, both with electric and gas-liquid coolant which are advisable to use on diesel generators of different capacities.

The heat exchanger works as follows. During operation of the power plant a cold coolant for example, fuel, under pressure through the inlet nozzle 1 enters the cavity "A" (Fig. 3). Cold coolant (at temperatures from -30 (Winter) to +30°C (Summer)) fills the cavity "A" and at the same time and under the influence of gravity acts on the piston 2 installed in the housing 3 of the heat exchanger. The piston begins to move downwards, compressing the spring 4, installed in the cavity "B" of the heat exchanger on the thrust plate 5, having a hole 6 for discharge through the drain nozzle 7 leaked into the cavity "B" of the fuel due to the insufficiently sealed piston seal 2 by the inner 8 and outer 9 cuff. Cold fuel is poorly supplied through the exhaust pipe 10 to the power plant and gradually fills the cavity "A" of the heat exchanger to the maximum. Inside the heat exchanger there is a tubes of the heater 11 which can be made in the form of a heat-electric heaters or hollow tubes for supplying a hot coolant heater inside the tubes. The tubes of the heater is fixed in the cover 12

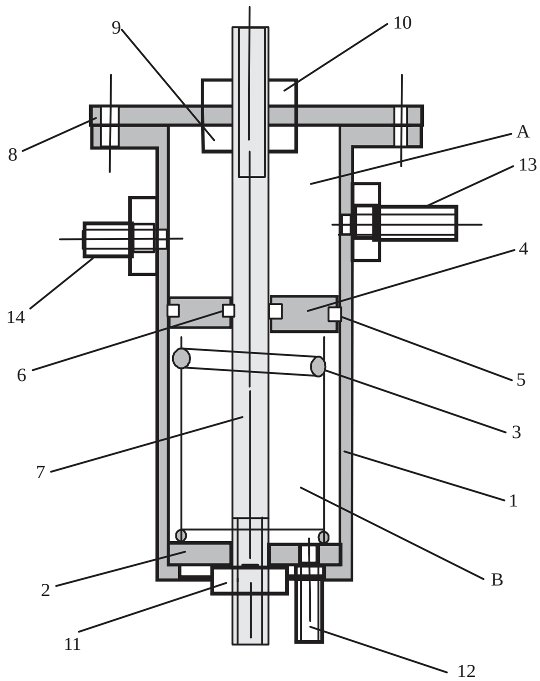

Fig. 3: Heat exchanger with variable surface area (1) Heat exchanger housing, (2) Stop plate, (3) Spring, (4) Piston, (5) An external sealing ring, (6) An internal sealing ring, (7) Heating tube, (8) Cover, (9) Hard nut, (10) Nut, (11) Adjusting nut, (12) Drain fitting, (13) Exhaust fitting and (14) Inlet fitting, A: the cavity of the fuel heating, B: adjusting cavity

of the heat exchanger by the lower 13 and upper 14 nuts. As the cavity "A" is filled, the height increases and with it the heating surface of 15 tubes. The cold coolant as the heating surface increases, heats up and changes the value of its density and reduces its weight, acting on the piston 2 and the spring 4 which begins when the cold coolant is heated to raise the piston 2 up and squeeze the heated coolant (fuel) from the cavity "A" into the exhaust nozzle 10, thereby self-regulating the optimal temperature of the cold coolant. To regulate the optimal temperature of heating the cold coolant in the heat exchanger, an adjusting nut 16 is installed with which it is possible to change the pre-compression of the spring 4. When the optimum heating temperature of the cold coolant is reached, the piston rises to the top and occupies a position in which it touches the rod 17 connected by means of a wire 18 to the hot coolant supply system through the inlet nozzle 1 and the hot coolant or electric heating current in the tubes of the heater 11.

In the course of calculations and experiments on the use of the heat exchanger, its placement in the diesel power supply system was justified in order to provide the required thermodynamic parameters.

The calculation of the cost of manufacturing a heat exchanger for heating fuel showed that the cost of piece production is 5-6 thousand rubles.

The system of biodiesel application with fuel heater has the highest efficiency. The payback period for the use of a diesel generator running on biofuel with a fuel heater is 5.7 months.

CONCLUSION

Methodologically, the interrelation of the effective parameters of diesel generator with the physico-chemical characteristics of the fuels. It is established that the influence of physical and chemical parameters has virtually no effect on the workflow. The efficiency of biofuel application is achieved mainly due to changes in the composition of the air-fuel mixture and redistribution of heat and heat in the process of fuel combustion. The constructive scheme is proved and the calculation-theoretical analysis of parameters of the fuel heater is executed. Calculations proved that the efficiency of heating the fuel takes place but the value of the effect is negligible and is 1.5-3%. In the course of laboratory studies temperature dependences of thermophysical parameters of diesel fuel, biodiesel and binary fuel were obtained. Motor tests of the diesel generator with the fuel supply system including the fuel heater were carried out. During the motor tests carried out under the conditions of load characteristics, it was found that the use of fuel heating in the diesel power system has a small technical and economic effect which is 3-6%. The use of a fuel heater in a diesel power system running on biodiesel is justified and gives fuel savings of between 4 and 6%. The results of the diesel engine tests on binary fuel B-20 showed that the use of such fuel is advisable than equipping the engine with a fuel heating system, since, its fuel efficiency indicators practically correspond to the diesel parameters when it is running on diesel fuel. The calculation of the cost of manufacturing a heat exchanger for heating fuel showed that the cost of piece production is 5-6 thousand rubles. Calculation of the economic efficiency of the use of biodiesel with a fuel heater in the diesel power system showed its high efficiency. The payback period from the use of a diesel generator running on biofuel with a fuel heater is 5.7 months.

ACKNOWLEDGEMENT

These studies were conducted at the Department of "Transport machines" of Penza State University and at the Department of "Thermal Power Systems" of the National Research Mordovia State University. Also, the novelty and efficiency of the proposed design is confirmed by the patent for the invention of the Russian Federation No. 2671610.

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