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IMPROVEMENT OF MIXING PROCESSES IN DIESEL ENGINES

The object of research is gas-dynamic vortex processes in heterogeneous polydisperse flows. One of the most problematic issues in engine building is the completeness of combustion and the rate of fuel burnout in the given coordinates on the allotted hourly interval in the combustion chamber. These indicators, in turn, determine stringent requirements for used fuels in terms of thermophysical parameters that affect sawing, evaporation and mixing with an oxidizer. In the course of the study, methods of mathematical modeling were used based on the theory of similarity. Methods have been developed for preparing a combustible mixture for detonation-free combustion of a cheap alternative fuel. A method for assessing the quality of spraying low cetane fuel is proposed. A mathematical model is obtained for calculating the change in the parameters of the quality of atomization and the differential characteristics of fuel injection. This is necessary for theoretical studies of gas-dynamic processes in additional power systems for diesel engines in an unsteady three-dimensional flow with variable parameters of a polydisperse flow of a combustible mixture. It has been proven that with a decrease in the camshaft rotational speed, the injection speed will be insufficient to achieve the required spray quality due to a decrease in the speed. This made it possible to redesign the additional system using a separate dual fuel supply. Research samples of an additional power supply system for the ЯМЗ–24 ОН diesel engine (Yaroslavl Motor Plant, Russia) have been developed. Comparative tests of the engine operation on stable gas condensate with the main fuel equipment and an additional system have been carried out. Oscillograms of the tests were obtained and analyzed.

The research results provided the basis for the use of low cetane cheap gas condensate in diesel engines. This will improve the economic, power and environmental performance of the engines. Compared to standard cetane fuels, the price of fuel will decrease by 40 %, engine power will increase by 20 %, and the environmental performance of exhaust gases will decrease by 10–30 %.

Keywords: *additional power supply system, fuel equipment, alternative fuel, atomization quality, induction period, combustion efficiency.*

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1. Introduction

For any heat engine, i.e. piston, gas turbine or other design, the problem of increasing the combustion efficiency is being solved for about a century, since economic, power and environmental indicators depend on it (completeness) [1]. In addition, no less important in relation to the indicated indicators, the completeness of combustion and the rate of fuel burnout in given coordinates on the allotted hourly interval in the combustion chamber determine stringent requirements for the used fuels in terms of thermophysical parameters affecting sawing, evaporation and mixing with an oxidizer [2, 3]. Hence, there are restrictions on the use of alternative fuels for heat engines, for example, as gas condensate, methanol, fuels with a narrow fractional composition of hydrocarbons, etc. [4–6]. Solving this problem will contribute to improving energy efficiency and conserving energy resources.

An acute shortage of fuel and this is no secret, has firmly taken its position and dictates prices for almost everything (water, bread, heat, etc.) and can become the main argument in special conditions. Hence, an important scientific and technical task of weakening this argument follows – to find opportunities and scientifically substantiate their implementation by preparing alternative fuels for combustion so that the power, economic and environmental indicators of the engines would be at the level of indicators, as when operating on standard fuels. In connection with the above, it becomes necessary to solve such problems as expanding the grade of fuels used in existing engines.

Thus, the development of a method for assessing the quality of spraying low cetane fuels is an urgent task. *The object of research* is gas-dynamic vortex processes in heterogeneous polydisperse flows. *The aim of research* is to improve the processes of mixture formation and combustion of low cetane complete in diesel engines.

2. Methods of research

Studies of the processes of preparing alternative fuel for combustion in diesel engines were carried out on the basis of the theory of vortex gas-dynamic mixture formation of a heterogeneous polydisperse flow [7, 8]. With the help of the theory of similarity, methods of mathematical modeling and the obtained experimental data, the possibility of using low cetane gas condensate fuel in diesel engines has been proved.

The solution of the above problem was carried out theoretically and experimentally using an additional power supply system in the form of a vortex evaporator-mixer [9, 10]. The device is suitable for all existing engines, which are made on any fuel, and for normal ranges of load and crankshaft speed. The experiment confirmed all theoretical conclusions.

3. Research results and discussion

Let's propose the solution of these problems by using an additional power system in the form of a vortex evaporator-mixer, which operates on the energy of exhaust gases or a gas turbocharger for the use of cheap fuel (stable gas condensate) and an increase in the thermal efficiency of a diesel engine (Fig. 1).

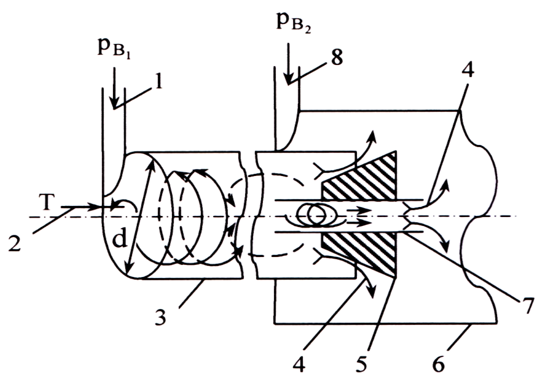

Fig. 1. Scheme of a vortex additional diesel power supply system: 1 – tangential air supply from the compressor of the gas turbocharger (GTC) (p_{B1}); 2 – fuel supply from the booster pump (T); 3 – cylindrical part of the vortex tube; 4 – streams of the aerosol prepared part of the working mixture; 5 – regulator of the mixture flow rate and rotation frequency of the vortex flow; 6 – diesel intake manifold; 7 – diaphragm of the vortex power supply system; 8 – tangential air supply (secondary vortex air flow from the GTC (p_{B2}))

Let's give an estimate of the change in the gas-dynamic parameters of the working mixture and the evaporation time to the aerosol state in the additional power supply system, which is made in the form of a vortex evaporator-mixer. The results of processing oscillograms of tests and calculations of the quality of sputtering of stable gas condensate were carried out by the main fuel equipment and an additional power supply system (Fig. 2). In this case, the working pressure in the evaporator-mixers was chosen equal to the boost pressure, which corresponds to the steady load mode of the ЯМЗ–24 ОН diesel engine (Yaroslavl Motor Plant, Russia), $N_e=380$ kW, $n=1200$ 1/min, $\Delta p^D=0.3$ MPa, $\delta_{ns}=190$ kN/m, $F_{vs}=80$ N, $F_{ns}=195$ N, $q_A^0=82$ mm^3/cycle, $q_A^D=121$ mm^3/cycle.

The quality of spraying of gas condensate fuel was assessed by counting on a smoked plate using a MIM-7 microscope (Russia). At the same time, the injection characteristics were synchronously oscillographic for the maximum load mode, at which the pressure at the inlet to the vortex evaporator-mixer was set equal to the boost pressure.

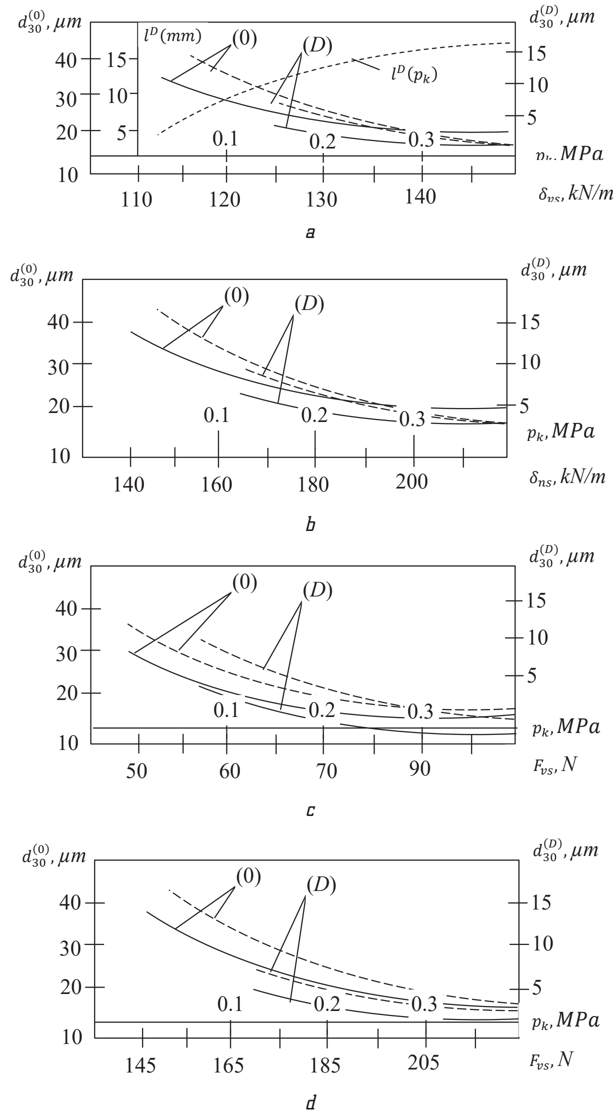

Fig. 2. Changing the quality of fuel atomization depending on: *a* – spring stiffness of the valve of the inflammatory dose (0) and vortex evaporator-mixer (*D*); *b* – nozzle spring stiffness; *c* – steady force of the valve spring; *d* – steady force of the nozzle atomizer spring: ---- – calculation; —— – experiment

Analysis of the results shows that the experimental and theoretical data do not have contradictions (Fig. 2). The nature of the change does not raise doubts when comparing such injection parameters as the leading and trailing edges of the differential injection characteristics. An increase in F_{vs}, F_{ns}, δ_{vs} and δ_{ns} when using gas condensate leads to a reduction in the fronts of the injection characteristics, at which the quality of atomization improves, and an increase in pressure in the vortex tube leads to a sharp increase in the angular velocity of the vortex. This increases the range of the torch l_g^D and the intensity of droplet evaporation.

A characteristic feature of mixing in evaporator-mixers is the vortex movement of air and fuel droplets, which increase the relative air velocity along the forming fuel droplet. At a boost pressure of 0.3 MPa and a vortex diameter of 0.022 m, the vortex frequency is in the range of $12\cdot10^3$ 1/min. A drop of fuel 20 μm in size until complete evaporation travels along a spiral of 120–250 m, depending on the change in air temperature at the inlet of the evaporator-mixer within 360–395 K. The torch range l^D reaches 15–17 mm (Fig. 2, *a*).

Particular attention is paid to the change in the injection parameters, without analyzing the change in the parameters of the fronts (leading and trailing) and the quality of spraying with fronts, which is the most qualitative assessment of the mixture formation process. If the leading and trailing edges increase, the d_{30} atomization quality deteriorates, which without an additional system increases the induction period of combustion. This argument is corrected by the presence of an aerosol mixture, which is formed by a vortex evaporator-mixer and with the help of which, during the compression process, the induction period acquires a nominal duration both when operating on low-cetane and standard fuels.

It should be noted that the starting qualities of a diesel engine (when starting a heated diesel engine) decreased by almost 2 times without increasing the cycle feed. The stability and completeness of combustion in the range of loads have increased dramatically in almost all modes of boost. Decrease in injection start pressure (F_{ns}<165 N), Fig. 2, *d*, leads to a deterioration in sputtering due to the growth of the leading and trailing edges of the supply ($\tau_2 > 1.3\tau_{2nom}$). At the same time, the rated power is reduced by 14–20 %, and the combustion severity remains at the same level as when operating on standard fuel.

Thus, obtaining aerosol quality of gas condensate fuel atomization using an additional diesel power supply system at 40–60 % of the nominal cycle feed allows increasing the speed and completeness of combustion of the entire feed due to the uniform distribution of fuel in the mixture from the beginning of compression to the injection of an inflammatory dose by the main fuel system.

The stability of the combustion process of low cetane fuels does not cause an increase in the rigidity of the process due to a sharp reduction in the induction period of combustion of the aerosol part of the charge with an increase in the density of the fresh charge and a decrease in the average volumetric diameter of a droplet from 30–40 microns to 0.5–2 microns.

4. Conclusions

Methods have been developed for preparing a combustible mixture for detonation-free combustion of a cheap alternative fuel in the form of a vortex evaporator-mixer, which works using the Ranque effect. Research samples of the additional power supply system for the ЯМЗ-24 ОН diesel engine have been designed and manufactured, and comparative tests of the engine operation on stable gas condensate with the main fuel equipment and the additional system have been carried out. It has been experimentally proven that during mixing in evaporator-mixers, as a result of the vortex movement of air and fuel droplets, the relative velocity, range and intensity of fuel evaporation increase. At a boost pressure of 0.3 MPa and a vortex diameter of 0.022 m, the vortex frequency is in the range of $12 \cdot 10^3$ 1/min. A drop of fuel 20 microns in size, until complete evaporation, travels along a spiral of 120–250 m, depending on the change in the air temperature at the inlet of the evaporator-mixer within 360–395 K. The torch range l^D reaches 15–17 mm.

A method for assessing the quality of spraying low cetane fuel is proposed. A mathematical model is obtained for calculating the change in parameters, the quality of atomization and the differential characteristics of fuel injection. It has been proven that the quality of atomization is determined by controllable arguments, which are the stiffness of the nozzle springs δ_{ns} and discharge valve δ_{vs}, the force of the pre-tightening of the valve F_{vs} and the nozzle needle F_{ns}.

The quality of gas condensate fuel cutting was investigated by counting on a smoked plate using a MIM-7 microscope and it was proved that the average diameter of a gas condensate fuel droplet was 0.5–2 microns, which corresponds to high-quality sawing. An increase in pressure in the vortex tube leads to a sharp increase in the angular velocity of the vortex, increases the mileage and evaporation rate of droplets, and improves the starting qualities of a diesel engine.

It has been proven that when using an additional power system, both on standard and on alternative fuels, the processes of atomization, evaporation and mixture formation are improved, which, in turn, increases the completeness of combustion. This improves the economic, power and environmental performance of the engines. Saving of standard fuel is about 10 %, the use of stable gas condensate will decrease by 40 % in price compared to standard high cetane fuels, engine power will increase by 20 %, and the amount of harmful emissions in exhaust gases will decrease by 10–30 %.

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