Improving the characteristics of atomized fuel jets for automotive engines

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Abstract. The fuel supply system is one of the most critical components of a diesel engine. The processes of fuel injection, atomization, and mixing are crucial in determining the efficiency, power output, economic performance, and environmental impact of the diesel engine's operation. Furthermore, with the deteriorating environmental conditions in major cities, the toxicity levels of diesel exhaust emissions have become a priority concern. The mathematical model of the injected fuel jet's development and combustion enables the direct calculation of various indicators related to the engine's operating process. The value of these results lies in the fact that numerical modeling allows for the investigation of the influence of injection characteristics, fuel supply timing and duration, as well as combustion chamber design parameters on the indicator diagram and cycle efficiency across a wide range of engine speed and load conditions.

1 Introduction

A promising direction for the development of internal combustion engines and, in particular, automotive tractor diesels is the use of new fuels that significantly improve the environmental performance of internal combustion engines. Despite the fact that attempts to use fuel as a fuel have been started relatively recently, fuel is considered to be one of the promising fuels for automotive tractor diesels.

The fuel is converted into fine droplets by high pressure. The characteristics of the atomized fuel jets can vary depending on the type of atomization system, fuel properties and process parameters. Here are some basic characteristics:

1. Fuel droplet size can vary from micrometers to several millimeters in diameter, smaller droplets can provide more efficient mixing of fuel with air and better combustion efficiency.
2. Uniform droplet volume distribution helps ensure even combustion of the fuel in the combustion chamber.
3. The angle at which the fuel is atomized affects the shape and structure of the resulting droplet cloud, this can be an important parameter in the design of the combustion system.
4. Rapid atomization of the fuel can be an important factor in ensuring good mixing with air and creating conditions for efficient combustion [1-2].

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5. Fuel pressure in the atomization system affects droplet size and velocity, high pressure can result in smaller droplets.
6. The physical and chemical properties of the fuel, such as viscosity, density, temperature stability, also affect the atomization process.
7. The atomization method used, such as throttle valve, injector, nozzle also affects the characteristics of the atomized fuel jets.
8. These parameters can be optimized according to the specific requirements of a particular engine or combustion system to achieve optimum efficiency and environmental friendliness.

2 Methodology

The object of mathematical modeling is selected fuel system of 4HK1-TCC diesel engine.

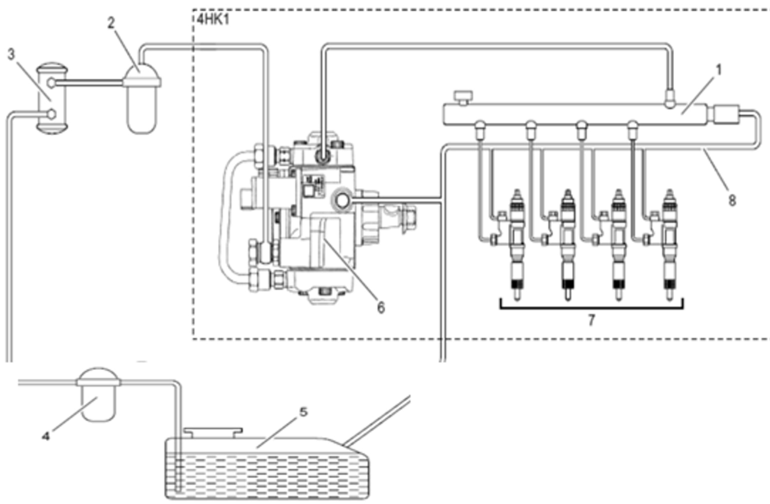

Fig. 1. Basic diagram of 4HK1-TCC diesel engine power supply. 1-fuel manifold, 2-fuel purification filter, 3-electromagnetic pump, 4-fuel coarse filter, 5-fuel tank, 6-fuel pump, 7-fuel injector, 8-drain fuel pipe.

The optimum droplet size depends on the specific conditions and requirements of a particular combustion system. The design and tuning of the fuel atomization system includes consideration of these factors to achieve the best performance and efficiency.

Careful tuning or selection of the proper nozzles is required to ensure optimal fuel atomization and improved mixing with air. Here are a few key aspects to consider when selecting or modifying nozzles for use with fuel, nozzles must have a specific geometry to ensure uniform fuel atomization [3-4].

Nozzles with a specific atomization angle that can be adjusted for optimal combustion chamber coverage, nozzle orifices are sized according to the physical properties of the fuel such as viscosity and density, too large orifices can result in inadequate atomization, while too small orifices can cause clogging or uneven combustion.

Materials that are resistant to the chemical attack of the fuel. Ensure that nozzles do not corrode or lose their properties with prolonged exposure to fuel. Fuel may require higher pressure in the injection system to ensure efficient atomization, use nozzles specifically designed for high pressure operation.

It may be necessary to adjust the injection angle for optimal mixing of fuel with air in the combustion chamber, design features of a particular engine and injection system, consider using a multi-point injection system for more even distribution of fuel in the engine cylinders. Check and thoroughly test injectors in real conditions to ensure their efficiency and reliability and optimize injector parameters based on the test results [5-6].

In diesel engines with volumetric mixing, these parameters are selected to ensure the most complete coverage of the combustion chamber by the fuel jets, the required fineness of atomization, uniform distribution of fuel droplets over the volume of the air charge, and to prevent fuel droplets from getting on the combustion chamber walls. The required orientation of fuel jets in the combustion chamber space is achieved by the appropriate location of sawing holes, and the fuel jet parameters are achieved by selecting the diameter and length of sawing holes. At the same time, a very important design parameter is the ratio of the length of the sawing hole l_p of the nozzle to its diameter d_p. It is explained by peculiarities of fuel flow through the sawing hole. In modern diesel fuel systems in the process of fuel supply fuel from the pump under high pressure enters the injector, acts on the needle 1 (Figure 1), raising it, flows through the annular gap 3 formed between the needle 1 and the body 2 and enters the cavity 4 under the needle 1, where the injection pressure p_{vpr} is set. Under this pressure the fuel enters the sawing hole 5 of the nozzle.

Table 1. 4HK1-TCC diesel engine atomizer parameters.

Atomizer characteristics	**Spray hole**	
	1	**2**
Angle of fuel jets in plan view α, deg.	142	320
Angle of fuel jets in plan view β, deg.	27.7	27.7
Length of atomizing opening l_p, *mm*	1.26	0.59
Division l_p/d_p	2.76	1.28
Spray hole diameter d_p, *mm*	0.457	
Equivalent flow area of the atomizer assembly $\mu_p f_p$	0.177	
Maximum nozzle needle lift $h_{u\,\max}$	0.25	

Of particular interest is a comparative analysis of these indicators in a wide range of operating modes characteristic of transport diesel engines. To assess the influence of division.

L_p/d_p on the parameters of sprayed fuel jets under different diesel operating modes, experimental studies were carried out of the geometric parameters of sawed fuel jets obtained in a divided diesel fuel system (see Figure 2 a), which includes a fuel pump and a nozzle from a sprayer (see Figure 2 b).

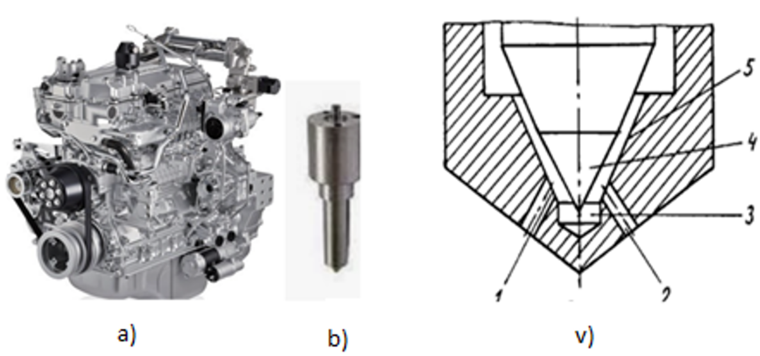

Fig. 2. 4HK1-TCC, atomizer, cross-sectional design diagrams of the atomizer.

The design diagrams of the sprayer are shown in Figure 2 some characteristics of the sprayer - in Table. 1. The sprayer has two spray holes. In the atomizer, the entrance edges 1 (see Figure 2) of the spray holes 2 are located in the volume 3 of the cavity under the nozzle needle 4 (in the well of the nozzle), and on the locking cone of the seat 5 (see Figure 2) the nozzle needles 4.

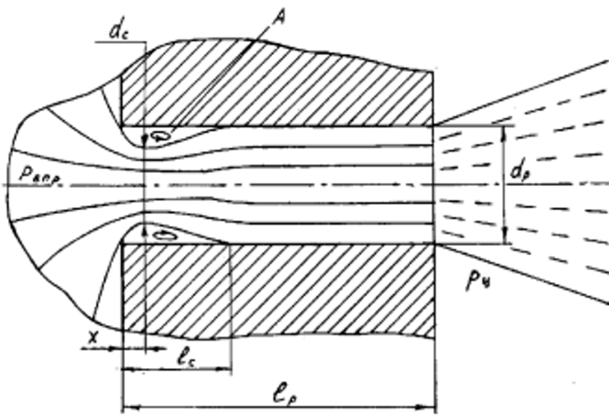

Fig. 3. Diagram of the injector nozzle with the geometric characteristics of the jets of sawn fuel.

The equivalent flow sections of the atomizer assembled with a needle are $\mu_p f_p$ = 0.176 mm^2 with a maximum needle lift h_u max = 0.24 mm. For the nozzles under study, the spray holes are made with a length l_p and a diameter d_p = 0.455 mm. Spray hole $d_к$ = 1.2 mm, diameter of the locking edge of the needle d_x = 3.0 mm, angles of the locking cones of the needle and seat, respectively, β_u = 60 and β_c = 59.

One of the important indicators of the quality of the fuel system performance is the stable residual pressure P_0 at the operating modes of the diesel engine An important indicator is the minimization of residual pressure fluctuations ΔP_0 when changing the operating mode and temperature [7-8].

From the Table 2 shows the instability of the static adjustment of $P_{ko.ob}$, which is largely eliminated in the design.

Table 2. Parameters of double acting injection valves.

Main valve opening pressure ΔP_{ko}, MPa ΔP_{ko}, MPa	~1
Check valve opening pressure $P_{ko.ob}$, MPa	1.5-1.7
Jet diameter, mm	1.95
Main valve diameter, mm	10
Diameter of the sealing surface of the check valve, mm	4.8

3 Results and discussion

As a result, rational ratios of the parameters of the double-acting injection valve were determined when the unit operates on fuel $d_j^2/d_{ok}^2 = 0{,}2 \ldots 0.26$, $\delta_{ok}/\delta = 0{,}25 \ldots 0.35$, $F_{ok}/F = 0.24 \ldots 0.33$, where (d_j - diameter of the nozzle in the main valve, d_{ok} - diameter of the check valve, δ_{ok} - stiffness of the check valve spring, δ - stiffness of the main valve spring, F_{ok} - pre-tightening force of the check valve spring, F - main valve pre-tightening force.

It is also shown that P_0 fluctuations at operation of the fuel apparatus with a double-acting valve are quite satisfactory (Δ_{P0}=0.25...0.28 MPa), at operation of the fuel apparatus with a standard valve Δ_{P0} increased ((Δ_{P0}=3.0...3.4 MPa). At such Δ_{P0} it is possible to form fuel apparatus ruptures at P_{0min} and undesirable under injections at P_{0max}, especially if we take into account the influence on the value of Δ_{P0} of technological tolerances on the parameters of the serial valve.

Due to the lower (compared to Diesel fuel) heat of combustion of the fuel, the mass cycle fuel supply has to be increased by a factor of about 1.5, which leads to an undesirable increase in the injection duration. In addition, it is important to note that for the same active stroke of the plunger, the mass fuel supply decreases. Experimental determination of the coefficient Km change (decrease) cycle feed (in mg / cycle) in the transition from diesel fuel to fuel showed that in the range of operating modes of the diesel varies within 1.3 ... 1.6, increasing with decreasing speed of the shaft fuel pump high pressure and load, especially great Km in the start-up mode (1.7 ... 2).

When installing needles into the body of the sprayer, its throughput is reduced. When flowing into a medium without backpressure, the equivalent flow sections $\mu_p f_p$ of the atomizer are 0.176 and 0.184 mm^2 (at maximum lift of the nozzle needle h_u max = 0.24 mm). With increasing back pressure, these sections increase and reach values of 0.21 and 0.216 mm^2, respectively, for values of $K_c < 1$. Thus, with the maximum lift of the nozzle needle, the atomizer had a slightly smaller effective area of the atomizer assembled with the needle $\mu_p f_p$.

A mathematical model for characterizing jets of atomized fuel is associated with the diameter of the spray holes (d_p, mm), the equivalent flow area of the atomizer assembly ($\mu_p f_p$),

$$\mu_p f_p = g(d_p, D, V\ DSD, \rho, \theta, C, L, Z) \quad (1)$$

in this equation, g is a function depending on the diameter of the spray hole and other parameters.

Raising the injector needle

$$h_i = h(d_p, \mu_p, f_p) \quad (2)$$

here h is a function depending on the diameter of the spray hole, equivalent to the flow area of the sprayer.

The jet characteristics of sprayers or injectors can include various parameters that describe the shape, size and dynamics of the jet. These parameters can be used to describe jet characteristics in a variety of engineering, agricultural, industrial and scientific applications where nozzles and nozzles are used to create or control fluid flows. The final set of parameters may depend on the specific nozzle type, application and task requirements. The jet characteristics of sprayers or injectors can include various parameters that describe the shape, size and dynamics of the jet.

Application of the developed mathematical models improves the characteristics of jets of sawn fuel by the following indicators of jet characteristics, jet diameter (D), jet speed (V), droplet diameter distribution (DSD), jet density (ρ), spray angle (θ), concentration (C), shape jet (Z), spray distance (L), drop frequency (F), jet energy (N).

4 Conclusion

Taking into account the above, the equations of unsteady movement of fuel in fuel lines can be written in the following form:

$$\left.\begin{aligned} \frac{\partial p}{\partial x} + \rho \frac{\partial c}{\partial t} + 2\rho k c = 0, \\ \frac{\partial c}{\partial x} + \frac{1}{\alpha^2 \rho} \frac{\partial p}{\partial t} = 0, \end{aligned}\right\} \quad (3)$$

here x is the current coordinate of the fuel line length, t is time, c is the speed of the fuel, a is the speed of sound in the fuel, ρ is the density, k is the hydraulic resistance factor.

These are equations (3) of dependence for specific jet properties and characteristics. In addition, the equations of conservation of mass, momentum, and energy can be used to more fully describe the dynamics of the jet. The development of such a model usually involves a combination of experiments and theoretical considerations.

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