Investigation of characteristics of diesel fuel atomization with a high-speed gas jet

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Abstract. Using the modern contactless interferometric method for determining the droplet diameter (IPI), a gas-drop flow was experimentally investigated when diesel fuel is atomized with a high-speed gas jet. The size distribution of fuel drops was obtained in different operating parameters. The dependences of drop sizes on regime parameters are revealed and analyzed.

1. Introduction

The task of high-quality and environmentally safe combustion of low-grade liquid hydrocarbon fuels (waste oils, refinery waste, etc.) is now gaining increasing relevance due to the impossibility of their secondary use. At the same time, traditional combustion methods and burners do not allow solving the problem, since the combustion of such fuels, often with a high content of impurities, leads to an increase in emissions of harmful combustion products, as well as to malfunctions of the burner device associated with clogging of spraying channels.

To solve this issue, a new method for burning low-quality liquid hydrocarbon fuels by spraying it with a high-speed jet of overheated water vapor [1] has been proposed and developed at IT SB RAS. A distinctive feature of this method is the lack of fuel contact with the nozzle, which allows one to avoid interruptions in the operation of the burner device associated with clogging of channels and coking of the nozzle surface. At the same time, overheated water vapor contributes to the combustion process due to its partial gasification, which leads to a decrease in the concentration of harmful emissions while maintaining complete combustion of the fuel in the burner [2].

In work [2] authors have studied the effect of spraying fuel with overheated water vapor and comparing it with air fuel spraying. It was shown that with different operating modes of the device (changes in steam/fuel or air/fuel consumption) there are various thermal indicators. The authors attributed these effects to changes in the aerodynamics of the flow in the mixing chamber due to various parameters of the spray jet supply. In the case of steam supply, with its presence in the mixture, it also affects the chemistry of the process.

However, it was not indicated in the work that the parameters of the generated combustible aerosols (the structure and dispersed composition) serve also as a fundamental criterion directly influencing the quality of fuel burnout. Nevertheless, the extreme complexity of interrelated physical processes that affect the characteristics of the formation of a gas-drop flow limits the possibilities of applying theoretical methods and requires the use of experimental methods. Therefore, obtaining detailed information is carried out using modern optical methods (SP, IPI) [3-4].

Thus, in order to expend understanding of the effect of various high-speed steam/air jet supply modes on the operation of the burner device, the generated gas-drop stream was studied in this work using the IPI method.
2. Experimental setup and technique
In this paper, the spraying of liquid hydrocarbons by a high-speed gas jet in a direct-flow burner (without burning) is studied on the example of diesel fuel. Air and superheated steam are used as a spraying phase.

The process of spraying and burning liquid fuel in the device under study is described in detail in [2]. Preliminary studies [5] of this burner design made it possible to determine the range of operating parameters for stable combustion of the fuel, in which the drop size distribution in the gas-drop flow was determined.

The characteristics of liquid fuel atomization with a high-speed gas jet were studied by a contactless optical method for flow diagnostics, namely by an interferometric method for determining drop diameters (Interferometric Particle Imaging – IPI) [3, 6]. The method is based on the registration of defocused particle images in the area illuminated by a laser sheet. This method allows determining the size (from 10 microns) and the position of spherical particles suspended in the flow. The scheme of the experimental setup is presented in Figure 1.

For experiments the measuring complex "Polis" was used. It includes the ImperX B4820-M CCD camera (resolution 4904 × 3280 pixels) and a Nikon macro lens with a focal length of 105 mm. To compress the image in one direction, an optical compression unit designed especially for this lens was used. The Nd:YAG QuantelEVG pulsed laser was used as the light source (wavelength of 532 nm, pulse energy of up to 145 MJ, pulse duration of 10 ns). ActualFlow software with IPI Kit was used for digital processing.

![Figure 1. Experimental setup for IPI measurements: 1 – nozzle; 2 – laser; 3 – camera; 4 – lens; 5 – optic compression unit; 6 – fuel pipe; 7 – steam generator; 8 – fuel nozzle; 9 – fuel filter.](image)

3. Results
For each studied mode, a series of 100 images were obtained. During processing, the particles identified in each image were taken into account (for normalization). Figure 2 shows the results of the study of drop size distribution when diesel fuel is sprayed with superheated (T = 350 °C) steam ($n_i$ is number of droplets with sizes from the $i$-th range in the $j$-th image, $N$ is total number of droplets identified by the algorithm in the $j$-th image, $j = 1…100$). The dependence on steam flow rate (Fig. 2-a) at constant fuel consumption ($F_f = 1.4$ kg/h) and the dependence on fuel flow rate (Fig. 2-b) at constant steam consumption ($F_v = 0.8$ kg/h) are presented.
As one can see, fuel flow rate does not affect the characteristics of the spray. With increasing steam flow rate and constant fuel flow rate, there is a slight decrease in the proportion of small particles. Apparently, this is due to a decrease in the interaction time (due to an increase in the speed of the steam jet) of the fuel with superheated steam: the droplets of fuel evaporate less. In turn, this fact does not affect the burning. From the data obtained, it follows that the characteristic size of droplets in the entire range of modes under study is 10–20 μm (Fig. 2). Such dispersion of fuel is sufficient for efficient combustion of diesel fuel [7], which indicates the prospect of the spray method under study.

Figure 3 shows the drop size distribution when diesel fuel is sprayed with air. Figure 3-a shows the distribution depending on air temperature. It is seen that the change in air temperature has no pronounced effect on the size distribution of fuel drops. A change in fuel flow rate at a fixed air flow rate (Figure 3-b) also does not lead to a change in the dispersed composition of the gas-drop flow in the studied range of parameters. It should be also noted that a change in the spraying medium (steam/air) does not affect the characteristics of the gas-drop flow.

**Conclusion**

In this paper, the gas-drop flow was experimentally investigated, using the modern contactless interferometric method for determining the droplet diameter (IPI), when spraying diesel fuel with a high-speed gas jet. In a wide range of operating modes corresponding to different combustion regimes, information was obtained on the size distribution of fuel drops. It is shown that the characteristic size of
the detected drops in all studied modes is 10–20 µm, which is sufficient for efficient combustion of liquid fuel. It was revealed that the change in the characteristics of the sprayed medium has no pronounced effect on the dispersed composition of the gas-droplet flow, and the combustion process is determined by stoichiometry.

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