Investigation of a promising method for liquid hydrocarbons spraying

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Abstract. Using the method of shadow photography, the disperse composition and the structure of the gas-drop flow when used crankcase oil is sprayed with a high-speed jet of heated air were investigated. In a wide range of regime parameters, the droplet size distributions were obtained. The gas temperature range and the distance from the nozzle at which the preferred droplet size in the flow is up to 20 μm were determined for the specified values of air pressure and fuel consumption.

At present, the important problem is the accumulation of large amount of substandard liquid hydrocarbons. The use of low-quality fuels such as used crankcase oil or crude oil in the production of energy requires the creation of efficient and environmentally safe combustion technologies. Gas-droplet fuel-air mixtures can be generated by spray nozzles of various types. To ensure the high efficiency of such devices, a detailed study of methods for controlling the characteristics of the gas-drop flow is required. Information on the velocity distribution and particle size in a two-phase jet is necessary for the scientific justification of the choice of optimal operating parameters.

In this paper a promising method of spraying liquid hydrocarbon fuel (used crankcase oil) with a high-speed air jet [1] is experimentally investigated. A distinctive feature of this method is that the fuel is supplied in the form of a jet into the high-speed flow of the carrier phase (heated compressed air) flowing out of the nozzle. Such a method of forming a finely dispersed gas-drop flow in practice has an important advantage: there is no contact between fuel and nozzle so coking of its surfaces and associated failures in the operation of the burner device are avoidable.

Using the shadow photography method [2], the structure and the disperse composition of a two-phase flow is investigated at spraying the used crankcase oil with an air jet. The scheme of the experimental setup is shown in figure 1. This method is based on taking a shadow photograph of an object having a refractive index, different from ambient medium. At that, behind the investigated object (relative to the camera) there is a diffuse light source with a uniform spatial distribution of intensity. The focusing plane of the camera lens is close to the object of investigation to obtain the greatest sharpness of the shadow photo. Digital analysis of the shadow image allows identifying the boundary and position of the object. This method allows measuring the droplet sizes within the range from 10 to 1000 μm.

In experiments, the CCD camera Videoscan 4021 (with a resolution of 2048 × 2048 pixels, a shooting frequency up to 1.25 Hz, and an exposure time of 28 ms) and the Tamron SP AF macro lens with a focal length of 180 mm were used to reduce the size of the measuring area to 10 × 10 mm with good spatial resolution (magnification 1.5:1). A background screen with a rhodamine-based
luminescent coating preliminarily illuminated by a defocused beam of a Nd:YAG QuantelEVG pulse laser (wavelength of 532 nm, pulse energy of up to 145 mJ, and pulse duration of 10 ns) was used as a light source. A threshold light filter (560 nm) whose bandwidth corresponds to the wavelength of light re-emitted by rhodamine was used to increase the shadow photo contrast. A coordinate-moving device with a positioning accuracy of 0.1 mm was used to move the camera along the axis of the nozzle that enabled examining the flow at different distances from the nozzle.

To create a high-speed gas jet compressed air was used. The air heating was carried out by a tubular electric heater installed inside the spiral air supply channel. Temperature control was carried out by thermocouples mounted on the heater body. The difference in the air temperature at the outlet from the heater and the temperature of the heater surface did not exceed 5 °C. The supply air pressure was adjusted using a reducer. The pressure inside the heater was monitored using a digital pressure sensor (measuring accuracy of 1 kPa). The fuel supply was provided by a fuel injector and a pump. The mass of the fuel was monitored using the electronic weights (limit of permissible error of 1 g).

Investigations of characteristics of the gas-drop flow were carried out under various operating conditions: air overpressure in the heater (1-6 atm) and fuel consumption (300-600 g / h) were varied. The temperature of air heating inside the heater was 25-550° C.

Figure 2 shows the typical shadow images of two-phase flows at the same pressure of air supplied to the injector and the same fuel consumption, but at different temperatures of the carrier phase. The pictures are taken for 4 consecutive measuring regions 10×10 mm along the nozzle axis. It can be seen that the efficiency of dispersing and mixing strongly depends on the temperature of air supplied from the heater. At a temperature of 25 °C up to a distance of 40 mm from the nozzle, large droplets and filamentary structures of the unfragmented liquid remain in the flow (figure 2-a). When the air is heated to 250 °C and higher at a distance of 20 mm, a more uniform finely dispersed gas-drop flow is formed (figure 2-b).

For digital processing of the obtained shadow images the "Bubbles Identification" algorithm, implemented in the ActualFlow software [3], was used. It includes high-pass filtering algorithm to identify the boundaries of images of registered objects, algorithm for binarization by a threshold value, and algorithm for determining the position and the diameter of spherical droplets. Figure 3-a shows a typical shadow photograph processed with the indicated algorithm (marks indicate the identified drops).

As a result of image processing, information on the dispersed composition of the fuel droplets was received under different spraying regimes. Figure 3-b shows the dispersed composition of droplets in the flow at a distance of 30 mm from the nozzle at different temperatures of the air supplied from the heater. Analysis of the results shows that the particle size depends on the air temperature: the fraction of fine particles in the flow (up to 20 μm) increases with increasing air temperature. At the air pressure of 3 atm., a temperature from 150 to 550°C and a fuel consumption of 300 g/h, the preferential particle
Figure 2. Shadow images of the flow (fuel consumption of 300 g/h, air pressure of 3 atm.) at different air temperature in the heater: (a) 25°C; (b) 250°C.

Figure 3. (a) An example of processing a shadow image of a gas-droplet stream; (b) distribution of droplets size at different air temperatures: 3 atm. pressure, fuel consumption of 300 g/h, \( N_i \) is the number of droplets with dimensions from a certain range, \( N \) is the total number of drops identified by the algorithm.

The size in the flow does not exceed 20 μm. It is noted that when the fuel consumption is increased or the air pressure is lowered, the dispersion efficiency decreases (the characteristic size of the droplets increases).

Conclusion

Using the method of shadow photography, the characteristics of spraying liquid hydrocarbon fuel by a high-speed gas jet have been studied. It is shown that the preheating of the carrier phase (up to 150°C and above) contributes to a significant increase in the spraying efficiency and uniformity of the flow. In view of the weak dependence of the disperse composition on the temperature in the range of 150-
550°C, it can be concluded that for effective dispersion it is sufficient to preheat the air to 150-250°C. It is shown that in this temperature range at an air pressure of 3 atm. and a fuel consumption of 300 g/h, a preferential particle size in the flow (up to 20 μm) is achieved. The characteristic distance from the nozzle on which the fine-dispersed flow is formed is 20-30 mm. Such characteristics of the gas-droplet flow ensure effective ignition and burning of the used crankcase oil.

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