Study of dispersed composition of spray during atomization of water-fuel emulsion with a superheated steam jet

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Abstract. Using the method of direct shadow photography the dispersed composition of fuel spray was studied when water-fuel emulsion is sprayed with the superheater steam jet. For emulsions with a mass water content of 5 and 10%, the characteristic droplet size in the flow is 1–2 μm and sufficient for effective combustion.

1. Introduction
High-quality dispersion of fuel is one of the important conditions for efficient combustion. It determines the efficiency of mixture formation, the stability of ignition, increases the rate of combustion and the completeness of fuel combustion, and affects the level of emission of toxic products. Thus, combustion in spray burners is a promising way to use low-grade liquid hydrocarbon fuels for energy production. However, an urgent task is to reduce the level of harmful emissions in combustion products when using such fuels.

One of the ways to solve this problem is combustion in the form of water-fuel emulsions. Adding water and steam during combustion is a known way to reduce harmful emissions and improve the quality of combustion [1]. The advantages of water-fuel emulsions are that they are not explosive and are not susceptible to spontaneous combustion; they demonstrate high completeness of combustion due to the occurrence of chemical reactions of water vapor with a carbon residue and can reduce the content of carcinogens, carbon monoxide, and soot in combustion products.

In this work, a high-speed superheated steam jet generated by a steam nozzle used in a direct-flow spray-type burner device [2] was applied to spray a water-fuel emulsion. The advantage of this method of fuel atomization is that there is no direct contact between the fuel and the hot surface of the nozzle, which avoids coking and malfunctions.

2. Experimental technique
The study of process of dispersing a water-fuel emulsion by a jet of superheated steam was carried out using a spray unit of a liquid-fuel burner, the diagram of which is shown in Figure 1-a. Figure 1-b shows a typical photograph of the combustion of the investigated emulsion in this device. For the research, we used an emulsion consisting of diesel fuel and water with a water content of 5 and 10% by weight. The homogeneous emulsion was achieved by repeated circulation of the water-fuel mixture through the fuel pump. Fuel was supplied to the spray unit directly at the outlet of the tank to prevent emulsion stratification.
Figure 1. (a) Scheme of the liquid fuel experimental burner. (b) Characteristic photo of combustion of water-fuel emulsion (10%).

The method of direct shadow photography [3] was used to determine the dispersed composition of the fuel spray. The ImperX B6620 CCD camera (shooting frequency of 2 Hz, resolution of 6600 × 4400 pixels) was used for digital recording of shadow images. For shooting with a high spatial magnification (7:1), the Infinity K2 Distamax long-focus lens with CF-2 attachment and 2x-NTX-tube amplifier was used. The size of one pixel in this case was 1 μm, and the size of the measuring area was 6.6×4.4 mm, so this method allowed identification of droplets as small as 1 μm. 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.

For digital processing of the obtained shadow images the "Bubbles Identification" algorithm, implemented in the ActualFlow software [4], 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 2 shows a typical shadow photograph processed with the indicated algorithm (marks indicate the identified drops).
Figures 3-4 show the size distribution of droplets in a spray for different water content in the emulsion. At that, there is no pronounced dependence of dispersed composition on operating characteristics (the flow rates of steam and fuel) for the studied regimes. The Sauter Mean Diameter, calculated as \[ \frac{\Sigma(n_iD_i^3)}{\Sigma(n_iD_i^2)} \] (where \( n_i \) is a number of droplets with diameter \( D_i \)) is close to 7 \( \mu \)m for every presented regime, which emphasizes the efficient atomization of water-fuel emulsion with the use of a high-speed superheated steam jet.

Figure 3. The size distributions of droplets in a fuel spray (5% water in emulsion): (a) Steam flow rate – 0.8 kg/h; (b) Fuel flow rate – 1.2 kg/h.
Figure 4. The size distributions of droplets in a fuel spray (10% water in emulsion): (a) Steam flow rate – 0.8 kg/h; (b) Fuel flow rate – 1.2 kg/h.

Conclusion
Using the method of direct shadow photography the dispersed composition of fuel spray was studied when water-fuel emulsion is sprayed with the superheater steam jet. For emulsions with a mass water content of 5 and 10%, the characteristic droplet size in the flow is 1–2 μm for different steam and fuel flowrates. Such a size is sufficient for effective combustion of water-fuel emulsion. Further research will be aimed at studying the processes of ignition and combustion of a water-fuel emulsion under various operating parameters.

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