Investigation of characteristics of a pneumatic nozzle as applied to coal-water fuel spraying

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Abstract. A gas-droplet flow, formed by spraying liquid with a pneumatic nozzle was studied in a wide range of parameters. Information on the distribution of particle sizes was obtained using the method of shadow photography. High-speed visualization of the flow was performed. The nozzle operating regimes of a steady gas-droplet flow generation were identified.

1. Introduction
In spite of the fact that in recent decades, the requirements for the level of NOx and SOx emissions at energy facilities have increased significantly, coal will remain the most important fuel and energy resource for a long time [1, 2]. Against this background, the “clean” coal technologies [2], designed to minimize the harmful effects of its use, have obtained an impetus for development.

One of such technologies is the use of water-coal fuel (WCF) [3]. This technology has a number of advantages as compared to traditional coal-dust combustion: WCF is not explosive and is not subject to self-ignition, it can be transported by pipelines, it has a high degree of combustion, and significant amount of water in this fuel allows reducing carcinogens, carbon monoxide, and soot in the combustion products by 70-80% [4]. At the same time, high watering is one of the main difficulties in the process of WCF ignition, since it requires preliminary heating of the furnace. This necessitates additional technical solutions and the use of highly reactive fuels. Ignition conditions depend on the dispersed composition of the fuel-air mixture. Therefore, it is urgent to study ways of organizing a stable finely dispersed gas-droplet flow for efficient combustion of water-coal fuel.

One of the stages in the development of devices for the WCF combustion is laboratory simulation. In this paper, the process of WCF spraying with a special pneumatic nozzle is studied using non-contact optical methods [5].

2. Experimental setup and technique
The process of liquid spraying with a pneumatic nozzle was studied experimentally on an experimental setup, whose photograph is shown in Figure 1-a. The main elements of setup are as follows: compressed air supply system (1) with flow meter (2); liquid supply system (3) with flow meter (4); pneumatic nozzle (5); optical section for non-contact measurements (6); liquid-trapping system (7); ventilation (8). Air ($Q_a$) and liquid ($Q_l$) flow rates are regulated using needle taps. Excessive air pressure in the nozzle ($p$) is registered by manometer (9).
To determine the dispersed composition of the gas-droplet flow, the direct shadow photography method was used. The following equipment was used to implement this method: an ImperX B-6620 digital camera for recording images with good spatial resolution of 6600x4400 pixels; long-focus microscopic lens to provide the required magnification (7:1); rhodamine-based background screen as a light source; pulsed laser for intense short-term illumination of the screen in order to obtain a contrast image. The optical system was tuned up so that 1 pixel of the image corresponded to 1 μm.

For high-speed flow visualization, a high-speed Photron FASTCAM Nova S12 type 1000K-M-32GB digital camera with a recording frequency of up to 1 MHz and minimum exposure of up to 0.208 μs was used. In full-frame mode (1024x1024 pixels), this camera allows shooting with a frequency of up to 12800 Hz.

Figure 1-b shows the scheme of the nozzle, where the measuring areas are marked with rectangles: 1 is the area of high-speed visualization, as the region of gas-droplet flow formation; 2, 3 are the areas of research by the method of shadow photography, as areas located in the ignition zone (in a real boiler) on the jet axis and at the periphery, respectively.

3. Results
Figure 2 shows the results of high-speed flow visualization. Visualization was carried out in area 1 (Fig. 1-b). Images were obtained for various regimes, the shooting frequency was 10 kHz, and the exposure time was 20 μs. The regime with the liquid (water) flow rate of 50 g/s and overpressure in the nozzle of 3 atm is shown in Figure 2-a. It is seen that a finely dispersed gas-droplet flow is formed. At the same time, large drops are formed at the jet periphery. In regimes when overpressure is 5 atm and higher (Fig. 2-b, c), a compact high-speed steady gas-droplet jet, consisting mainly of small droplets, is formed. Thus, these regimes are favorable for the practical use of the nozzle.
Figure 2. Photos taken with a high-speed camera: (a) $p = 3$ atm, $Q_l = 50$ g/s; (a) $p = 5$ atm., $Q_l = 50$ g/s; (a) $p = 5$ atm., $Q_l = 100$ g/s.

The results of flow investigation by the direct shadow photography are presented in Figure 3. A regime with overpressure in the nozzle of 5 atm and liquid flow rate of 100 g/s is shown. Figure 3-a shows a characteristic shadow photograph taken for this regime in area 2 (Fig. 1-b) on the flow axis at a distance of 350 mm from the nozzle (region of WCF ignition in a real boiler). It is seen that the flow is homogeneous without pronounced large drops. Figure 3-b shows the size distribution of droplets obtained by processing this image. Up to 90% of all drops are less than 10 $\mu$m in size. This indicates effectiveness of the studied nozzle for spraying liquids.

Figure 3. Typical shadow photograph (a) and size distribution of droplets obtained by processing this image (b).

Conclusion

A gas-droplet flow, formed by spraying liquid with a pneumatic nozzle, was studied in a wide range of regimes using high-speed visualization. It has been determined that at overpressure in the nozzle of 5 atm and higher, the regimes for the formation of a compact stable fine-dispersed gas-droplet jet are generated. In practice, this will contribute to the effective combustion of the water-coal fuel. The dispersed composition of the generated flow was studied by the method of shadow photography. The characteristic particle size in the flow is $2-10 \mu$m, which indicates the efficiency of liquid spraying by the studied nozzle. These results will be used in further mathematical modeling of the process under study.
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