Investigation of characteristics of the liquid-fluid burner device spraying unit using IPI method

I S Anufriev, E Yu Shadrin*, E P Kopyev and O V Sharypov
Kutateladze Institute of Thermophysics SB RAS, Novosibirsk, Russia

*E-mail: evgen_zavita@mail.ru

Abstract. Two-phase gas-droplet flow at used transmission oil spraying by high-speed air jet has been experimentally investigated using interferometric method (IPI). Data on the dispersed composition of the air-fuel jet have been obtained in a wide range of operating parameters (air and fuel flow rates) corresponding to the area of stable operation of the burner. Dependences of droplet sizes in the flow on the regime parameters have been established.

1. Introduction
One of the ways to efficient and environmentally safe use of low-quality liquid fuels (such as used oils, oil refineries, etc.) is its burning with a preliminary spraying. The available technologies of burning often do not allow the use of such fuels as the main ones, since the combustion of fuel with a high content of impurities leads to increased emission of harmful combustion products, as well as to malfunctioning of the burner, associated with clogging channels of spray devices. Developing methods for creating dispersed gas-liquid flows with specified parameters is an important scientific and technical task. It requires a detailed study of spray devices, i.e. nozzles, using laboratory modeling. Obtaining detailed information about the structure and dispersed composition of the gas-droplet fuel jet using modern optical methods (SP, IPI) [1-2] is important for optimizing the equipment and the combustion process as a whole.

An original method of fuel supply and mixing it with an oxidizing agent was proposed and developed at IT SB RAS, namely, a method of spraying liquid hydrocarbon fuel by a gas jet [3]. A distinctive feature of this approach is that the fuel and the spraying medium (carrier phase) are not pre-mixed with each other: the gas supplies from the nozzle in the form of a jet into which liquid fuel is fed, resulting in a fine gas-drop stream. In practice, this is an important advantage, since there is no contact of the fuel with the nozzle, which prevents coking of its surfaces and subsequent malfunction of the burner when using highly viscous fuels, or fuels with a low degree of purification.

Since the characteristics of burning liquid hydrocarbon fuel in burner devices often depend on the quality of its preparation and further dispersion by spraying devices, an appropriate crushing of the supplied fuel allows for a more complete combustion reaction by increasing the contact area of the fuel and oxidizer. Therefore, when creating spray nozzles for burners, detailed information is required on the characteristics of the generated gas-droplet flow. However, the extreme complexity of interrelated physical processes that influence the characteristics of the formation of a gas-droplet flow limits the possibilities of applying theoretical methods and requires the application of experimental methods.
2. Experimental setup and technique

In this paper, the atomization of liquid hydrocarbons by a high-speed gas jet in a direct-flow burner (without combustion) is studied by the example of used transmission oil and air.

The process of atomization and combustion of liquid fuels is as follows (Fig. 1). The air flows out of the nozzle in the form of a jet. Liquid fuel flows freely into its base and interacts with the high-speed air jet to form a finely dispersed gas-droplet flow. Dimensions provide the power of the burner, necessary and sufficient for research under the laboratory conditions. The nozzle is made as a cover with a hole. The nozzle diameter is chosen so that for a given angle of jet opening, it is possible to create the necessary aerodynamic clamp that ensures formation of a recirculation zone near the burner outlet, which is a flame stabilizer. The design provides for a natural air flow from the atmosphere to the reaction zone through the side openings in the lower part of the casing. Atmospheric air is required to ignite liquid fuels. Fuel is supplied to the burner through the fuel line. The nozzle is made according to the technical requirements for the nozzles of the steering rocket engines. The diameter (0.6 mm) and length of the nozzle (4 mm) are the decisive parameters for stable operation of the device and maintaining the thermal balance, including ensuring the desired angle of jet opening and the required velocity of the carrier phase for effective dispersion of liquid.

Preliminary studies [4] of this burner design allowed determining the conditions for stable combustion of used oil. The investigation concerned the regimes in the range of air flow rate $F_a$ corresponding to the working range of the laboratory burner device. The limits of variation of fuel flow rate $F_f$ corresponded to the permissible power of the burner in laboratory measurements. The temperature of air in the experiments was $T_s=25..550 \, ^\circ C$. The measurements were carried out in the flow region, shown in Fig. 1 with the red rectangle, where the dispersed fuel evaporated intensively and mixed with air.

The characteristics of liquid fuel spraying by a high-speed air jet were studied by a non-contact optical method for diagnosing flows, namely an interferometric method for determining droplet diameters (IPI) [1, 5]. The method is based on the registration of defocused droplet images, illuminated by a laser sheet. According to the scattering theory [5], the light reflected and two times refracted by the spherical surface of the droplet creates interference fringes in the droplet images. Their frequency directly depends on the droplet diameter. Digital analysis of the obtained images allows determining the
position and size of the droplets suspended in the stream. This method serves to measure particles with sizes from 10 microns.

To conduct the experiments, the “Polis” measuring complex was used. It includes: CCD camera ImperX B4820-M (resolution 4904×3280 pixels, shooting frequency of 3.2 Hz, and minimum inter-frame delay of 200 ns) and a Nikon macro lens with a focal length of 105 mm. To compress the image in one direction, an optical compression unit specially designed for the lens was used. A pulsed laser Nd:YAG QuantelEVG (wavelength – 532 nm, pulse energy – up to 145 MJ, and pulse duration – 10 ns) was used as a light source.

In digital processing, the ActualFlow software with IPI Kit package was used to implement the following algorithms:

- Image search algorithm.
- Frequency calculation algorithm.
- Algorithm for screening images.
- Calibration algorithm.

3. Results

For each regime under study, a series of 100 images was obtained. The processing took into account the total distribution of particles in all images, normalized by the total number of identified particles. As a result of IPI-image processing, detailed information has been obtained on the disperse composition in the measuring area of the gas-droplet flow when used oil is sprayed by a high-speed air jet depending on the operating parameters (fuel flow rate and air flow rate and temperature).

Figure 2. The dispersed composition of fuel droplets formed at oil spraying by an air jet in the atmosphere at oil temperature of 40°C:

- (a) $F_a = 1.12$ kg/h, $T_a = 23$°C;
- (b) $F_f = 1.6$ kg/h, $T_f = 250$°C;
- (c) $P_a = 5.5$ bar, $F_f = 1.2$ kg/h.

$(n_i$ – number of droplets with the sizes from the $i$-th range in the $j$-th image, $N$ – total number of droplets identified by the algorithm in the $j$-th image, $j = 1…200$)

It is shown that the predominant particle size in all studied regimes is in the range of 10-20 µm (Fig. 2), which is a sufficient condition for efficient fuel combustion [6] and indicates the advantages of the method used for dispersing liquid fuel.

With changes in fuel flow rate in the studied range (at a fixed air flow rate) droplet sizes do not change (Fig. 2-a). Therefore, flameout and high CO content in combustion products observed in certain modes are not related to the dispersed composition of the spray. Changing of air flow rate (Fig. 2-b) and air temperature (Fig. 2-c) also has a slight effect on the dispersion composition of the flow in the studied range of parameters.
Conclusion
In this work, using the interferometric method for determining the droplet diameter, the gas-droplet flow has been experimentally studied at used transmission oil spraying by a high-speed air jet in a direct-flow burner (without combustion). In a wide range of operating parameters corresponding to different combustion modes, size distributions of fuel droplets have been obtained. The characteristic size of the identified droplets in all studied regimes is shown to be 10-20 µm, which is sufficient for efficient combustion of liquid fuel. It has been established that the combustion regimes with high content of CO in the products are not associated with the dispersed composition of the spray, and depend on stoichiometry. The obtained experimental data are in demand for numerical calculations of the combustion processes of dispersed liquid hydrocarbons.

Acknowledgments
This work was carried out within the framework of the state assignment for the IT SB RAS (Reg. No. AAAA-A17-117022850029-9).

References
[1] Kuznetsov G V, Strizhak P A, Volkov R S and Vysokomornaya O V 2016 Int. J. Therm. Sci. 108 218–34
[2] Watanabe H, Shoji Y, Yamagaki T, Hayashi J, Akamatsu F and Okazaki K 2016 Fuel 182 259–65
[3] Vigriyanov M S, Alekseenko S V, Sharypov O V and Anufriev I S 2019 RF Patent 2678150 (in Russian)
[4] I S Anufriev, Kopyev E P, Sharypov O V, Arsent'ev S S, Vigriyanov M S and Osintsev Ya A 2018 J. Phys.: Conf. Series 1105 012036
[5] Lozhkin Yu A, Markovich D M, Pakhomov M A and Terekhov V I 2014 Thermophys. Aeromech. 21 (3) 294–307
[6] Danis A M, Namer I and Cernansky N P 1988 Combust. Flame 74 (3) 285–94