Development of the system for quantitative gas-liquid flow visualization

A V Kuchmenko, D A Koshelev, N M Skornyakova and P P Shcherbakov

National Research University «Moscow Power Engineering Institute», Krasnokazarmennaya 17, Moscow, 111250, Russia

E-mail: ann.131@yandex.ru

Abstract The paper is concerned with the developing of an optical-electronic complex for visualization and quantification of the gas-liquid flow from the nozzle using the particle image velocimetry method depending on various flow parameters. Selection of optical elements for experimental research was based on the possibility of visualizing the flow, determining its type, opening angle, and also obtaining vector velocity fields in the plane under study, on the basis of which the gas-liquid flow drops velocities dependencies on the coordinates in given sections of the vector field were constructed.

1. Introduction
For a long time, numerous applications of nozzles in industry have been known. To date, there are methods for calculating nozzles and the results of theoretical and experimental studies used in various fields of science and industry, but it is often quite difficult in experimental studies to determine the flow parameters by contact methods [1-8]. The solution to these difficulties can be the use of contactless optical methods which are widely used due to modern high-speed video cameras, lenses with various parameters, software and the rapid optical methods development for researching liquid and gas flows.

The particle image velocimetry technique (PIV) is one of the optical contactless methods of fluxes research, allowing to recorder instantaneous velocity fields in the measurement plane. The experimental data obtained using the PIV method will also make it possible in the future to simply determine the flow structure from the nozzle (full or hollow cone), as well as the jet opening angle [9-12]. The use of the purposed technique can significantly reduce the time of the experiment, which often plays an important role in the complex technological processes.

The main aim of the work is to develop a contactless optical-electronic complex for the quantitative visualization of a dispersed gas-liquid flow, the production and processing of experimental images. Based on the images obtained, the nozzle type (full or hollow cone), the opening angle of the jet were determined, and the vectorial velocity field was obtained, the dependences of the velocities of the flow drops in various sections were plotted.
2. Experimental setup
For the implementation of the experimental setup to the flow study using the method of particle image velocimetry, the presence of a laser sheet and tracers is necessary [13-15]. The light from the laser module passes through a cylindrical lens, which forms a diverging laser sheet, exposing the flow in a certain section. A blue diode laser with 450 nm wavelength and 1000 mW was used as a laser module.

To determine the flow rates, tracers are introduced using the spraying system for oils and other liquids, the speed of which determines the flow rate, but in this experiment drops from the gas-liquid flow itself appeared as tracers. The main criteria related to tracer are small size, spherical shape, and smooth surface. The recording of the stream propagation was carried out using a high-speed camera which registers the illuminated stream against a darkened background with a certain frame rate. We used a monochrome high-speed camera Fastec HiSpec 1 with a CMOS matrix, which allows obtaining images at speeds up to 506 frames per second at a resolution of 1280 × 1024 pixels. This model of a video camera has high sensitivity - 3200 ISO and the ability to shoot up to 112000 frames per second. For the correct construction of the object under study vector velocity field, the number of recorded frames per second is at least 500. On the basis of the first series of experiments, the necessary parameters of the lens to obtain high-quality images were determined. The parameters studied at this stage include a sufficient lens aperture ratio (f1.2-close) and a focusing range (0.3 - infinity). A lens that satisfies all of the above parameters is the Navitar DO1212 with a focal length of 12 mm. The main task of the measurement system, the collection and processing of information during the experiment is to receive data from the camera, as well as registering the data (recording in computer memory). In addition, in real-time mode, the stream is displayed on the screen to select the required shooting parameters (recording speed, light quality, etc.). Further processing of the obtained data and analysis of the results of the experiment. Image processing allows calculating the displacement of particles between two successively recorded frames using cross-correlation analysis, which uniquely determines the flow rate in a given area.

3. Experimental data processing
Using experimental images (visually), it is possible to determine an equally important parameter - the type of jet from the nozzle. Figure 1 (a), (b) shows photographs of the flows from two different nozzles.

![Figure 1. Flow from two different injectors:](image)
a – nozzle type full cone; b – hollow cone type nozzle.
It was obtained that the injector being investigated is of a full cone type. Such nozzles are used to a greater extent for cooling in view of the fact that the force of the blow flow from it is significantly less than that of other types, and at the same time it allows the liquid to be evenly distributed on the surface of the cooled object.

The angle of jet opening was determined from the geometry of the jet due to the program JMicroVision. The method of determining the angle of jet aperture from the nozzle is shown in figure 2.

![Figure 2. Determination of the jet aperture angle from the nozzle.](image)

To determine the reliable width of the flow, the JMicroVision program allows building a brightness distribution, which allows you to consider the brightness threshold of the flow structure to correctly determine the aperture angle of aperture. In this case, the threshold corresponded to 25 (≈ 10% of maximum brightness 255). And according to the graph of the brightness distribution in the section, the jet geometry was determined. Table 1 shows the obtained values of the jet aperture angle at pressures of flow in 2 and 4 bars.

![Figure 3. The flux brightness distribution (the yellow line indicates the brightness threshold of the flux structure).](image)
The jet opening angle from the nozzle for 2 and 4 bar is not significantly different and has values of 17 and 18 degrees, respectively. When conducting experimental studies, processing was performed to determine the quantitative flow characteristics from the nozzle. Using cross-correlation processing, the velocity field was constructed in the cross section of the gas-liquid flow from the nozzle. Processing was carried out using the PIVview program with the following parameters: polling area - 64 pixels; step - 32 pixels, 50% overlap, the algorithm for determining the correlation peak - 3-point Gaussian approximation. The function of eliminating erroneous vectors was also applied. Baseline experimental data are shown in figure 4.

![Figure 4](image1.png)

*Figure 4. The flow from the nozzle at a 2 and 4 bar pressure (on the left - at a pressure of 2 bar, on the right - at a pressure of 4 bar).*

The result of constructing the vector velocity field is shown in figure 5.

![Figure 5](image2.png)

*Figure 5. The result of constructing the flow velocity field from the nozzle at a pressure of 2 and 4 bar (on the left - at a pressure of 2 bar, on the right - at a pressure of 4 bar)*

Figure 6 shows the lines for constructing the values of velocity in the cross section X and Y of the gas-liquid flow.

![Figure 6](image3.png)

*Figure 6. Sections along which the values of flow rates from the nozzle were determined at a 2 and 4 bar pressure (to the left - at a pressure of 2 bar, to the right - at a pressure of 4 bar).*

According to the obtained values of the velocities of the flow drops, the dependences of the average velocity of the drops on the Z and Y coordinates were plotted.
Figure 7. The dependence of the velocity of the particle flow from the nozzle from the coordinates Z, Y (pressure 2 bar):
(a) – dependence of particle flow velocities on Z coordinate; (b) – dependence of particle flow velocities on Y coordinate.

Figure 8. The dependence of the velocity of the particle flow from the nozzle from the coordinates Z, Y (pressure 4 bar):
(a) – dependence of particle flow velocities on Z coordinate; (b) – dependence of particle flow velocities on Y coordinate.
The dependences obtained are in good agreement with the data given in [16]. Dependencies for 2 and 4 bars pressure turned out to be similar. Considering the dependence of speed on the Z coordinate, it is possible to conclude that at the initial stage the flow is a zone of continuous liquid flow, then small particles slow down and begin to fall. Medium particles combine with each other and move, gradually acquiring greater speed, and then slow down and also fall down. The dependence of the velocity on the Y coordinate shows the asymmetry of the jet, since the velocity is different at different points of this section.

4. Conclusion
An optical-electronic device was developed to enable the dispersed flow quantitative visualization. The efficiency of the installation of high-speed visualization and quantification was tested at two flow pressures. Test and experimental images were obtained that are necessary for carrying out the algorithm of the PIV method. After analyzing the experimental data, it was found that the best for the experiment is a high-aperture lens. For this case, experimental images were processed, which were used to determine the jet opening angle, nozzle type, flow velocities distribution at two pressures, and dependences of the velocities of the flow drops in various sections were plotted. It should be stressed that this installation will need to be upgraded to study various nozzle types, which is related to the size of the droplets themselves, as well as the type of jet from the nozzles, but these improvements will not be global.

Acknowledgments
The work was carried out with the financial support of the RNF (project 16-19-10457-P).

References
[1] Hasselmann K, Aus Der Wiesche S.and Kenig E Y 2019 Optimization of Piecewise Conical Nozzles: Theory and Application Journal of Fluids Engineering, Transactions of the ASME 141(12) 121202
[2] Bang B-H, Kim Y-I, Jeong S, Yarin A L and Yoon S S 2019 Theoretical model for swirling thin film flows inside nozzles with converging-diverging shapes Applied Mathematical Modelling 76 607-16
[3] Gregorio E, Torrent X, Planas S and Rosell-Polo J R 2019 Assessment of spray drift potential reduction for hollow-cone nozzles: Part 2. LiDAR technique Science of the Total Environment 687 967-77
[4] Maly M, Sapik M, Czejpek O, Katolicky J and Jedelsky J 2019 Effect of spill orifice geometry on spray and control characteristics of spill-return pressure-swirl atomizers Experimental Thermal and Fluid Science 106, 159-70
[5] Persico G, Rodriguez-Fernandez P and Romei A 2019 High-Fidelity Shape Optimization of Non-Conventional Turbomachinery by Surrogate Evolutionary Strategies Journal of Turbomachinery 141(8), 081010
[6] Oh S Y, Shin J S, Kim T S, Chung C-M and Lee J 2019 Effect of nozzle types on the laser cutting performance for 60-mm-thick stainless steel Optics and Laser Technology 119,105607
[7] Feng S, Xiao L, Ge Z, Du X and Wu H 2019 Parameter analysis of atomized droplets sprayed evaporation in flue gas flow International Journal of Heat and Mass Transfer 129 936-52
[8] Mirshahi M, Yan Y and Nouri J M 2015 Influence of cavitation on near nozzle exit spray Journal of Physics: Conference Series 656(1), 012093
[9] Maly M, Sapik M, Czejpek O, Katolicky J and Jedelsky J 2019 Effect of spill orifice geometry on spray and control characteristics of spill-return pressure-swirl atomizers Experimental Thermal and Fluid Science 106, 159-70
[10] Hillamo H, Anttinen T, Aronsson U, Andersson O and Johansson B 2011 Flow field measurements inside a piston bowl of a heavy-duty diesel engine SAE Technical Papers
[11] Sergeev D A 2011 etry using particle images (PIV-methods) in laboratory modeling of geophysical flows Bulletin of Nizhny Novgorod University. N.I. Lobachevsky 4 (2) 522 - 24.
[12] Knysh Yu A, Redkin E S and Dmitriev D N 2011 Experimental study of a swirling gas jet by the method of digital tracer visualization Bulletin of the Samara State Aerospace University. Academician S.P. Korolova 5(29) 11-17
[13] Varaksin A Yu, Protasov M V., Marinichev D V and Vasiliev N V 2015 Analysis of tracer particle parameters for optical diagnostics of vortex flows Measuring equipment 6 46-9
[14] Bernhard Wienke 2015 PIV uncertainty quantification from correlation statistics Measurement Science and Technology 26(7)
[15] Tokarev M P, Markovich D M and Bilsky A V 2007 Adaptive particle image processing algorithms for calculating instantaneous velocity fields Computational Technologies 12 (3)
[16] Eskov A V, Svistula A E, Cherepov O D and et all 2006 The method for determining the dispersed composition of droplets of a jet of sprayed liquid: Patent RU 2277442 № 16