The study of the hydrodynamics of bubble downflow at small gas-content by means of PIV / PFBI

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Abstract. Experiments on evaluation of the effect of bubbles on the hydrodynamic structure of two-phase bubbly downflow were carried out by means of PIV / PLIF method. Experiments were performed at Re = 5000 and gas flow rate ratio $\beta = 1\%$. Data were obtained on the distribution of liquid velocity and its fluctuations, as well as on the mean bubble diameter. The results were processed using a computer bubble detection algorithm. To validate the received data, they were compared with the results obtained in [1] for the same pipe using electrochemical method. A good agreement was found for R.M.S. of liquid velocity distribution for different methods.

1. Introduction
Two-phase gas-liquid flows are widely used in the energy sector, in oil refining industries, in various fields of the chemical industry, etc. In vertical channels, streams are divided into ascending and descending ones. In case of two-phase gas-liquid flows the local hydrodynamic structures of such flows are different. Currently, there are many works devoted to the study of downward bubble flows.

It is shown in [2], that in ascending flows, the bubbles tend to migrate to the pipe wall. In downward ones, bubbles are displaced to the center of the pipe, which leads to the formation of a bubble-free liquid layer near the wall [3, 4]. The distribution of the gas phase in the cross section of the channel affects the distribution of liquid velocity, and hence the most important characteristics of the equipment: hydraulic resistance and heat transfer.

Combining optical methods (PIV) with computer vision algorithms is a topical task. This allows obtaining information about the local flow characteristics; there is the possibility of a deeper study of the contribution of bubbles to the formation of turbulent structures in a liquid flow. There are some papers in the literature regarding the development of bubble detection methods and liquid flow properties using PIV/PLIF/PFBI [5–8]. Different approaches for detection of bubbles including neural networks are used in these studies.

The aim of this work is to study the structure of a gas-liquid downward flow in a pipe, as well as the effect of gas bubbles on the flow structure and turbulence at a low Reynolds number. The data obtained can be used to study the optimization of technological processes.

2. Experimental setup
Velocity profiles and its pulsations were measured using the "Polis-PIV" particle image velocimetry (PIV) experimental system. The scheme of the experimental setup is shown in Figure 1. The test liquid (distilled water) from tank 1 was supplied by centrifugal pump 2 to the test section, consisting of pipes with an inner diameter of 20 mm. The liquid flow was divided into two pressure lines. The liquid velocity
in each line was controlled by valves 3 and 5, the flow rate was measured by flow meters 4 and 6. The liquid was supplied by the pump into a special design mixer 7, where gas was introduced through thin capillaries. They were glued into Plexiglass insert with an inner diameter of 20 mm. The gas flow was controlled by microcontroller 8. Measurements using PIV were carried out in the test section 9 using laser 10 and digital camera. To prevent optical distortion, the Plexiglass box filled with immersion liquid (distilled water) was installed.

We used fluorescent particles from polymethyl methacrylate filled with rhodamine B manufactured by Dantec Dynamics (size distribution of 1–20 μm, and wavelength range of 550–700 nm). An optical filter was used to prevent glares from bubbles’ surfaces in the final images. Image processing was performed using "ActualFlow" software. To recognize bubbles in the image obtained using the PIV method, the program code based on the Hough transform was developed. This method allowed detecting straight and curved lines in grayscale or color images. It also served to specify the parameters of a family of curves and to search for the image of the set of curves of a given family (for the example circles). This relatively simple method appeared to be good for the search of nearly spherical bubbles on the flow images.

![Experimental setup diagram](image)

**Figure 1.** Experimental setup. 1 – tank; 2 – pump; 3, 5 – valve; 4, 6 – flow meter; 7 – mixer; 8 – microcontroller; 9 – optical section; 10 – laser.

3. **Experimental results**

The recognition of bubbles on images of a two-phase flow allows optimizing the determination of the velocity vectors for each region in the image. In the absence of bubble recognition, some tracers can be hidden or distorted by the contours of the bubble, which subsequently affects the construction of the velocity profile. Especially it is important for higher moments (R.M.S., Reynolds stresses, e.g.). This is
due to the appearance of “outliers”, which, with further averaging, change the real value of the velocity in each section of the channel. The main drawback of existing algorithms is their low efficiency or complexity. Therefore, many bubbles remain unrecognized, which causes an increase in the uncertainty in the experiment.

The recognition process takes place in several steps. At the first stage, the average image intensity is subtracted, which serves as a preparation for converting a color image into a binary one. After converting the image to binary, the magnification of the intensity is set to highlight more contours of the bubbles and detect tracers. After that the Hough transform is applied to the image. Figures 2 and 3 show the used algorithm run on experimental data with a submillimeter bubble size and larger than millimeter ones.

As can be seen from Figures 2 and 3, this algorithm allows us to detect about 90% of the number of bubbles in the original image, which indicates its good efficiency.

After the bubble’s recognition procedure, images of bubbles were subtracted from experimental images. The diameters of bubbles were multiplied by the factor of 1.5 during this procedure [5]. Therefore, bubble images were changed to black circles before the image processing by means of PIV algorithms.

**Figure 2.** Identification of “small” bubbles in the flow: (a) – initial image after subtraction of average intensity; (b) – identified images of bubbles.

**Figure 3.** Identification of “large” bubbles in the flow: (a) – initial image after subtraction of average intensity; (b) – identified images of bubbles.
This allows determining the velocity vectors only in the regions free of bubbles and reducing the uncertainty in determining the velocity caused by tracers in the projection of bubbles. When processing data obtained using PIV algorithms, there is a difference in the measurement uncertainty of the statistical flow parameters (the higher is the moment, the higher is the uncertainty). In addition, higher moments require analysis of a larger number of paired images [6]. In order to verify the results obtained in this study, R.M.S. of velocity is compared with data previously obtained in the same pipe using the electrochemical method [1]. The work [1] presents the results with the same gas flow rate ratio and slightly higher liquid flow rate. Mean diameters of bubbles are close in both studies and are of about 2 mm. We obtain a good agreement for results carried out by means of PIV and electrochemical method both for near wall and central part of the pipe. This allows considering the used method successful. Near the pipe wall the fluctuations are the same as for the case of a single-phase flow, which is typical for downflow with low void fractions. In the central region of the pipe the presence of bubbles leads to an increase in liquid velocity fluctuations, which relates to flow turbulization by bubbles.

Conclusions
The experimental study of liquid flow hydrodynamics in the bubbly downflow was carried out by means of PIV/PLIF system. The “Polis-PIV” system was used. The algorithm to detect bubbles in the flow was developed. This algorithm was used to delete the images of individual bubbles from the initial images of the two-phase flow before the use of PIV correlation algorithms. The comparison between our data and the results of Kashinsky et. al., which was obtained by electrochemical method was performed. The similar results have been obtained in both cases. The presence of bubbles in the flow leads to the increase in liquid velocity fluctuations in the central part of the pipe in comparison with the single-phase flow. The proposed method can be used to determine different flow characteristics (mean and R.M.S. liquid velocity, sizes of bubbles, its velocities and local void fraction) in bubbly flows with near spherical bubbles and low void fractions. To study flows with large void fraction or elliptical bubbles more complex algorithms should be developed based on novel approaches of image processing including neural networks.

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