Motion characteristics of bubbles behind a sudden channel expansion

A V Chinak, I A Evdokimenko, D V Kulikov and P D Lobanov
Kutateladze Institute of Thermophysics SB RAS, Novosibirsk, 630090, Ak. Lavrentiev Ave., 1, Russia
E-mail: lobanov@itp.nsc.ru

Abstract. Characteristics of movement of gas bubbles behind a sudden channel expansion were studied experimentally. The data on the distribution of the gas phase and speed of movement of bubbles were obtained. It is shown that at a distance from the sudden channel expansion the bubbles slow down, which relates to the slowing down of liquid due to an increase in the flow cross section. After the reattachment point, the bubbles move along a more curved path than upstream. It is shown that bubble clusters can form in the flow recovery zone. The velocity distribution in the channel was studied by means of laser Doppler anemometry (LDA).

1. Introduction
An important problem in the creation of energy-efficient equipment is the study of passive heat transfer intensifiers. Devices with flow separation are often used for this purpose. Such devices are simple and reliable, therefore they are often used in various technical devices, including high-energy equipment and burner chambers.

One of the simplest examples of such equipment is a round tube with a sudden expansion. Due to intensive vortex formation after expansion, a significant intensification of heat exchange processes occurs. Despite a rather large amount of research, a number of questions are still open even for single-phase flow. Studies of the local structure of a two-phase gas-liquid flow, and especially heat exchange in such flows, are practically absent in the literature.

Therefore, an urgent task is to conduct studies on the structure of a bubble gas-liquid flow in pipes with expansion, distribution of velocities of the liquid and dispersed phases, local gas content, size of bubbles and effect of gas additives on heat transfer behind the ledge.

Bubbly flows behind a sudden expansion in a horizontal channel were studied in [1, 2]. The pressure loss, void fraction, bubble size, as well as the averaged and fluctuation velocities of phases were measured in these investigations. Measurements in the horizontal flow of the air–oil mixture were performed in [3]. But a lot of questions about two-phase flow in a sudden channel expansion still remain open.

The purpose of this study is to perform investigations of velocity and void fraction distribution of bubbles behind the sudden channel expansion. Modern methods of image processing were used in order to reconstruct trajectories of individual bubbles in two-phase bubbly flow.

2. Experimental setup
The test section of the stand is a slot channel made of Plexiglass with dimensions of the internal cavity of 200x1000x20 mm. To create a sudden expansion, a Plexiglas plate is fixed inside the channel.
allows to form a step (see Figure 1a). In this study the step height H was 12 mm, the channel heights before and after the expansion (H1 and H2) were 8 and 20 mm respectively.

The test section was horizontally fixed on a frame of machine-made aluminium profiles, which ensures convenient fixing of the elements of the stand and optical system and simple reconfiguration (Figure 1b). Ultrasonic flow meter KARAT-520-32-0 was used to measure the flow rate of the test liquid. To supply the test liquid, centrifugal pump Grundfos CHI 4-40 was utilized. The frequency of pump rotation is set by a frequency converter PumpMaster PM-P540. The flow rate of the liquid through the test section varies between 0-5300 t/h, which corresponds to the channel Reynolds number of up to 12400. The photograph of the test section of the experimental setup is shown in Figure 1b. The gas phase was added to the carrier liquid stream through a single capillary. It was located in the centre of the channel at a distance of 150 mm from the entrance. The capillary was directed streamwise. The tip of the capillary was located 400 mm upstream the step. The gas flow rate was fixed as 0.83 ml/sec.

Figure 1. Experimental setup. Scheme of the test section (a) and photograph of two-phase flow (b).

3. Experimental results

An experimental study of the characteristics of the gas phase motion after a sudden expansion of the channel was carried out. The experiments were performed in distilled water. High-speed shadow video capture was conducted. Modern methods of processing and tracking the particles were used to identify individual bubbles in the flow and to determine the characteristics of their motion for the collected images. The description of the image analysis procedure can be found in [4]. The similar procedure included image improvement, binarization, determination of intensity gradients, and correlation analysis was performed in this study. This allowed us to obtain the motion characteristics of bubbles behind a sudden channel expansion.

Figure 2 shows data on the velocity distribution of individual bubbles along the length and width of the sudden expansion of a flat horizontal channel with the step height H=12 mm at a distance from the expansion zone x of up to 10 H. Here L is a line along the channel width (L=0.03m is a channel centerline position). It is obvious that rebuilding the flow after a sudden expansion of the channel leads to a decrease in the maximum velocity of liquid. Therefore, with increasing distance from the step (in the figures from left to right), there is a decrease in the velocity of bubbles, as well as the carrier liquid. An important feature is the transition of bubbles in the recirculation zone of the flow to a more curved trajectory, which is apparently caused by a high degree of flow perturbation.

The local void fraction distribution behind the step is shown in Figure 3. Void fraction level is shown on the right parts of the figures. For all considered Reynolds numbers (Re = 6600…12400), there is a tendency to increase the local void fraction with increasing distance from the step. Apparently, this is caused by the slowing down of the bubbles and their interaction with the vortex structures and return flow near the bottom wall of the channel. The formation of bubble clusters often occurs in the flow recovery zone in our experiments.

As shown by visualization of the streamlines, made in a single-phase flow by means of a laser knife, the location of areas with a minimum speed of bubble movement and the highest gas content approximately corresponds to the end of the recirculation area. It is found that for a single-phase flow, the location of the flow separation point is approximately 7–8 H from the step. This is in a good agreement with [1, 2].
The histograms of bubble diameters are presented in Figure 4. The mean bubble diameter in our experiments was about 3 mm. Bubbles were a little smaller for upper Reynolds number because of higher liquid velocity near capillary tip.

In addition, measurements of velocity distribution behind the sudden channel expansion were carried up by means of laser Doppler anemometry (LDA). LAD 05 system developed at Kutateladze Institute of Thermophysics SB RAS. The study was carried out in a single-phase flow. The results are shown in Figure 5. Here $y$ is a distance from the bottom wall of the channel and $Y$ is the channel height. The Reynolds number is 6600. The distances from the sudden expansion are marked in right down parts of the figures. The slowdown of liquid velocity near the top wall of the channel can be clearly seen. The negative values of the mean liquid velocity in the recirculation zone are lost at a distance of about 7-8 $H$ from the step. This is in a good agreement with our observations obtained using visualization of the flow structure.

![Figure 2. Velocity distribution of bubbles behind the sudden channel expansion: a – Re = 6600; b – Re = 12400.](image)

![Figure 3. Void fraction distribution behind the sudden channel expansion: a – Re = 6600; b – Re = 12400.](image)
Conclusions
Using the method of high-speed shadow video, the characteristics of the movement of gas bubbles behind the sudden channel expansion were studied. The recognition of images of bubbles and their trajectories was based on modern algorithms of machine vision. The data about trajectories of individual bubbles in the flow and void fraction distribution in the channel cross section were obtained. In order to get detailed information, the study of liquid velocity distribution was carried out by means of lased Doppler anemometry.

Acknowledgements
The work was performed with the partial financial support of the Russian Foundation for Basic Research, project No 18-08-00477 (two-phase bubbly flow) and the Ministry of Science and Higher Education of the Russian Federation, state contract with IT SB RAS III.22.7.3. (AAAA-A18-118051690120-2), for LDA measurements.

References
[1] Aloui F, Souhar M 1966 Int. J. Multiph. Flow. 22 651–65
[2] Rinne A, Loth R 1996 Exp. Therm. Fluid Sci. 13 152–66
[3] Ahmed W H, Ching C Y, Shoukri M 2008 Int. J. Heat Fluid Flow. 29 194–206
[4] Chinak A V, Lobanov P D, Plyashkevich V A and Badazhkov D V 2018 J. Phys.: Conf. Ser. 1105 012071