An experimental investigation of gas-liquid flow characteristics in the microchannel

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Abstract. The two-phase gas-liquid flow regimes in the horizontal rectangular microchannel using the high-speed video camera and dual-laser scanning were studied. Experiments were carried out in the microchannel with cross section 217x370 μm for the water-nitrogen mixture. The T-shaped mixer was used for gas-liquid flow formation. The influence of T-shaped entrance on the length of a gas and liquid bridges in the microchannel was established. The total pressure drop was measured in the microchannel taking into account the distribution of the gas and liquid bridges.

1. Introduction
Multiphase microsystems based on microchannels are of great interest for a variety of applications. The ever-rising demands of the energy efficiency industry, energy efficient and environmentally benign, have necessitated the need for highly efficient compact reactors and process equipment. This led to rapid development of micro-reactors and micro-fluidic devices in past few years. The gas-liquid two-phase flow in the microchannels is an important research area for the multiphase systems [1-3]. In previous years, a lot of works has been done on experimental characterization of gas-liquid flows in microchannels by using different experimental techniques to understand the effects of various operating and design parameters (gas and liquid velocities, physical properties, channel configuration) on the flow regimes [4, 5]. The T shaped mixer is one of the widely used geometries to introduce the gas and liquid phases in the microchannels. In particular, the Taylor flow regime was investigated in detail with different channel geometries and flow configurations [6]. The method of laser scanning was used in [7, 8] for determining characteristics of the gas-liquid flows.

The objective of this work is experimentally studying the mechanism of gas-liquid flow formation in rectangular horizontal microchannel 217x370 μm with T-shaped mixer. Using the high-speed video camera and dual-laser scanning was defined the main flow regimes in the microchannel.

2. Experimental equipment and methods
The experimental setup for the study gas-liquid flow in the rectangular horizontal microchannel is shown in figure 1. The working gas is nitrogen which is fed from the high-pressure reservoir (1) via the control valve and gas flow meter (3) to the test section (5). Water flows from the high-pressure tank (2) through the flow meter (3) and further into the T-shaped mixer (4) at the inlet of the experimental test section (5). Experimental section is the microchannel, assembled from glued glass.
and aluminum plates with total length 30 cm. The hydraulic diameter is much smaller than the capillary constant.

The study of two-phase gas-liquid flow regimes was conducted using the method of dual laser scanning. Two lasers (7) are positioned so that the laser beams illuminate one side of the rectangular channel. We used two lenses to change the diameter of the laser spot. The aperture is used to reduce the diameter of the laser beam. The lasers are powered using voltage source (8). The intensity of transmitted light is measured with photodiodes (6) arranged at the opposite side of the channel. The electric voltage from the photodiodes is analyzed using high-speed ADC and processed on the computer over time frame from one to three minutes. The first laser is located at a distance of 8.5 cm from the inlet. Second laser is located at a distance of 24 cm from the inlet for observing stable gas-liquid flow. Flow regimes are also registered using the high-speed camera (10).

3. Two-phase gas-liquid flow in microchannel

High-speed video shows, that the periodic slug flow with elongated gas bubbles (EB), transition flow (T) and annular flow (A) are the main flow regimes in the microchannel with cross section 217x370 μm. The depth of the microchannel is 217 μm, the width of the microchannel is 370 μm. Elongated bubble flow regime (EB) is characterized by the periodicity of the optical signal from the photodiode. Elongated bubble flow is observed in the range of superficial liquid and gas velocities $J_{\text{liq}} = 0.035 \div 0.104 \text{ m/s}$, $J_{\text{gas}} = 0.083 \div 0.830 \text{ m/s}$. The elongated bubble flow is characterized by the periodicity of gas bubbles and liquid bridges. Transition flow (T) is observed in the range of superficial liquid and gas velocities $J_{\text{liq}} = 0.035 \div 0.104 \text{ m/s}$, $J_{\text{gas}} = 0.664 \div 18.534 \text{ m/s}$. Such flow is not periodic, liquid bridges appear by combining of disturbances waves on the short opposite sides of the microchannel and destroy by combining gas bubble-slugs. Annular flow (A) is observed in the range of superficial liquid and gas velocities $J_{\text{liq}} = 0.035 \text{ m/s}$, $J_{\text{gas}} = 19.38 \div 20.65 \text{ m/s}$. There is no movement of an elongated bubble in this flow regime. The liquid flows in the liquid film with numerous waves along the walls of the microchannel.

The gas-liquid mixing process was observed using high-speed video for the microchannel 217x370 μm with the internal T-shaped entrance for the elongated bubble (EB) flow regime, figure 2.
The formation of the periodic elongated bubble in the microchannel is associated with capillary phenomena in the T-shaped entrance. The main stages of the formation of a two-phase flow in a T-shaped inlet for the superficial liquid and gas velocities $J_{\text{liq}} = 0.035 \text{ m/s}$, $J_{\text{gas}} = 0.083 \text{ m/s}$ presented in figure 2. It can be seen that a sequence of gas and liquid bridges is realized, the length of which depends on the input parameters of the T-shaped mixer.

Figure 3 (a) shows the comparison of the gas bridges lengths for elongated bubble flow regime (EB) with the model [9]. Experimental points were obtained using double-beam laser scanning (triangles) and high-speed video camera (circles). The model [9] predicts well the distribution of gas bridges obtained in the experiments. A comparison of the gas bridges lengths with the model [10] was made in the work. The comparison of experimental and theoretical data presented in figure 3 (b). The comparison of the gas bridges lengths was made in the range of superficial liquid and gas velocities $J_{\text{liq}} = 0.032 - 0.16 \text{ m/s}$, $J_{\text{gas}} = 0.083 - 0.664 \text{ m/s}$.

4. Pressure drop

The pressure drop was measured in the horizontal microchannel 217x370 $\mu\text{m}$. The pressure drop was measured by the pressure sensor MDDF-U with measurement limit from -0.1 MPa to 0.5 MPa. The pressure drop was investigated for the single-phase and two-phase flow up to 30 kPa. This restriction associated with the possibility of destruction of the microchannel for the high pressure.

The dependence of the friction factor on the mixture Reynolds number, determined by the model [11] presented in figure 4 (a). It is evident that the experimental data for single-phase flow correspond to the calculations for the homogeneous model [11] and the model [12], whereas for the two-phase flow they are substantially higher. The experimental data tend to the homogeneous model [11] for large Reynolds numbers in the annular flow region. The comparison of the pressure drop with the modified phenomenological model [13] for the elongated bubble flow regime, taking into account the distribution of the gas and liquid bridges lengths presented on the figure 4 (a) by the dark circles. The model [13] was modified for the rectangular microchannel by the method [14]. The modification consisted in using the Poiseuille number for a rectangular channel and calculating the capillary pressure in such a channel. Instead of the Poiseuille number $Po = \frac{f^*Re}{16}$ for the round channel, it was used the coefficient $15.08$, which was determined for the rectangular microchannel.

The pressure drop comparison of experimental and theoretical data in the microchannel presented in figure 4 (b) according to the model [13]. The experimental data correspond to the theoretical data with an error of not more than $\pm 20\%$. This suggests that the pressure drop is largely determined by the length of gas and liquid bridge in the microchannel with a transverse dimension substantially less than the capillary constant.
5. Conclusions

It was observed that the regime with elongated gas bubbles, transition flow and annular flow are the main patterns for a microchannel with the hydraulic diameter substantially less than the capillary constant. The influence of liquid and gas flow rates in T-mixer on the local characteristics of the gas-liquid flow in the microchannel were obtained with the help of high-speed visualization. The distribution of gas bridges was obtained in the experiments using double-beam laser scanning and high-speed video camera. A significant effect of capillary forces on the friction factor was determined in the paper. The method of calculating the friction factor for two-phase gas-liquid flow in the rectangular microchannel is experimentally substantiated.

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