Experimental study of local void fraction distribution in bubble flow in rod assembly

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In this work an experimental study of local void fraction distribution in square arrangement rod bundle channel 3 * 3 under bubble flow regime was carried out. Measurements were performed with conductivity probe help, which was introduced into the flow through an angular or side rod at an angle of 15° to the flow. This method made it possible to determine the local void fraction close to the walls of the rods and in the narrow gap between them. Measurements have shown that a dome-shaped profile of local void fraction is realized in the gap between the side rod and the central one, while a saddle-shaped distribution of the void fraction is observed on the line connecting the central and angular rods. Also the effect of the spacer grid on the distribution of the gas phase in the channel was shown.

1. Introduction
A number of studies of domestic and foreign authors are devoted to experimental investigations of the dispersed gas-liquid flow structure [1–5], but these experiments were carried out in channels of simple geometry. The development of theoretical and numerical models of gas-liquid flows is hampered by the lack of sufficient experimental information obtained for various flow conditions. In the last 5-10 years, there has been a noticeable tendency of transition of leading groups, which for many years conducted researches on two-phase flows in pipes, to studies in channels used in modern technologies. So, for example, annular channels and assemblies of vertical rods — simulators of fuel elements are used to study flows in relation to the modeling of fluid flow in fuel assemblies of modern reactor installations. For such channels, a detailed experimental study of hydrodynamics and heat transfer has been carried out for the flow of single-phase fluid in the assembly of vertical rods [6–9]. Criterial relationships have been obtained for calculating the hydraulic resistance coefficient, heat transfer coefficient, and critical heat flux. At the same time, the two-phase flow in such channels remains insufficiently explored.

Numerical codes designed to predict emergencies in nuclear reactors are usually based on two-fluid models. Reliable experimental data of gas phase distribution in the fuel assembly channel are necessary both for the compilation of the closure relations and for the verification of the models. There is a number of works devoted to this topic. So in works [10, 11] the void fraction averaged over the volume in the rod assembly was measured using pressure transducers. The paper [12] presents the distribution of gas content in the assembly averaged over the area, obtained using the X-ray scanner system. In [13], the volume-averaged gas content was measured by an impedance sensor. In addition to the works devoted to the measurement of averaged gas content, there are also studies which were devoted to measurements of local void fraction. Such experiments are carried out using optical or conductivity probe. In [14], measurements of the local gas content by an electric resistance probe were
carried out. The effect of spacer grid on the measured parameters was shown. In [15], was measured as averaged parameters using a gamma densitometer but also the local gas content using an optical sensor. Due to the method of introducing the probe into the test channel in the above works, the local void fraction was measured only on the line between the two rows of rods in the square layout assembly. In works [16, 17], more detailed studies of local gas content around a rod in an assembly are presented. But in these researches, the probe design did not allow measurements near the walls of the rods and in the narrow gaps between them.

In this work, due to the conductivity sensor introduction into the flow through one of the rods, it became possible to conduct a detailed measurement of local void fraction distribution near the walls of the rods and in narrow gaps between them.

2. Experimental apparatus and technique
The scheme of the experimental setup is presented on Fig. 1. The setup is a flow loop closed for liquid and open for gas. From the pump 1, the working liquid is fed into the channel 2 (Plexiglass tube of square section, 40 mm wide and 1800 mm long). Nine rods were mounted in the channel supported by four spacer grids. The cross section of the working channel is shown in Fig. 2. The bubbles generator 3 was installed at the bottom section of the channel. The liquid flow rate was defined by the pressure drop on flow orifice meter 4. The same way by the pressure drop on gas orifice meter 5 the gas volumetric flow rate was determined. The bubble mixture was fed into the tank 7 of the separator from the outlet of the working channel through a flexible plastic pipe 6. There the phases dividing were occurred. Then through the return pipe 9 the liquid returned to the main tank 8. The temperature of the liquid in the tank was kept constant and equal to 22 ± 0.1°C with the help of a system of thermal stabilization consisting of heater 10, valve 11, coil 12, thermocouple 13 and regulator 14. The resistance thermometer 15 was installed in the supply pipe to control the temperature of the fluid at the entrance to the test channel.

The test liquid was distilled water with the addition of potassium ferri- and ferrocyanide (0.01 N) and sodium carbonate (0.25 M) dissolved in it. The experiments were carried out at superficial liquid velocities $V_L$ in the range from 0.4 to 1 m/s, corresponding to Reynolds numbers $Re = 4000 - 11000$.
The hydraulic diameter was determined as the ratio of four areas of channel cross-sections to its perimeter $D = 4S/P = 9.7$ mm. Volumetric gas flow rate ratio $\beta$ was defined as $\beta = \frac{V_G}{(V_G + V_L)}$, where $V_G$ is superficial gas velocity. During the experiment, the gas content varied in the range from 3 to 7%.

The conductivity probe was used to measure the local void fraction. The experimental technique was in detail described in [18]. The probe at an angle of 15° was inserted with the aid of a traversing device into the flow through a hole in the side or angular rod of the assembly as shown in Fig. 3. This method made it possible to measure local parameters near the walls of the rods and in the narrow gap between them.

3. Results and discussion

As a result of the experiments, local void fraction distributions were obtained on the lines connecting central and lateral, as well as central and angular rods of the assembly, as shown in Fig. 4, with different liquid and gas flow rate parameters. The distribution of local void fraction in a narrow gap between the rods shown on Fig. 5. The distribution has a bell-shaped profile near the spacer grid, but at higher distance from the grid it becomes more filled. At large Reynolds numbers and low gas flow rate the distribution has minimum. Figure 6 shows the distribution of local gas content between central and angular rods. Near the spacer grid a bell-shaped profile is observed, as in the previous cases. But at some distance from the spacer grid, saddle-shaped void fraction profiles are realized. Besides the distribution maxima become more manifest with an increase of the Reynolds number and a decrease of gas flow rate. Probably, the distribution pattern far from the spacer grid is primarily related to the dispersion of the gas phase. If the bubble size is comparable to the size of the gap along which it moves, then the distribution will be bell-shaped. If the bubble is small enough compared to the size of the subchannel, the distribution will be saddle-shaped, which is typical for upward bubbly flows in pipes [1]. But this assumption must also be verified by optical methods.
Figure 5. Distribution of local void fraction in «A» configuration.

Figure 6. Distribution of local void fraction in «B» configuration.
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