Distribution of wall shear stress for a bubbly flow in rod assembly

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Abstract. The work is devoted to the experimental study of the wall shear stress in the vertical assembly of rods in a square arrangement for a bubble flow. The measurements were carried out using the electrodiffusion technique. The data obtained during the experiment show that the void fraction has a significant effect on the flow structure near the walls of the rods. The change in wall shear stress with distance from the spacer grid does not occur monotonously, in contrast to the single-phase case.

1. Introduction

Two-phase bubbly flows are very often found both in natural phenomena and in technical applications, therefore, the interest in studying such flows has always been rather high. A lot of investigations are devoted to the study of the movement of gas-liquid bubble mixtures in pipes and channels of simple geometry. The studies have shown the effect of gas content and dispersion of the gas phase on the hydraulic resistance, heat and mass transfer [1-3]. There are also some works devoted to the numerical simulation of gas-liquid mixtures motion [4, 5]. However, the models obtained for pipes cannot be directly applied (mimicked) in channels with more complex geometry, for example, such as rod assemblies. Therefore it is necessary to experimentally study the structure of a two-phase flow in channels of complex geometry. The investigation of bubble flows in rod assemblies is due to the need to improve the efficiency and safety of nuclear power plants. Currently, single-phase flows in rod assemblies have been studied in great detail. It allows validating the numerical models [6, 7]. A number of leading scientific groups (Tomiyama, Ishii, Prasser) carry out studies of two-phase bubble flows in the fuel assembly channels [8 - 10]. In these works, the main attention is paid to the distribution of local void fraction and the effect of spacer and mixing grids on it. Using the electrodiffusion method, one can obtain information on the turbulent flow structure near the walls of the assembly rods. The application of this technique for measuring wall shear stress in gas-liquid flows under various conditions is performed in [11, 12]. However, in the literature there is no information on the wall shear stress in the rod assemblies in the bubble flow.

Thus, the objective of this study is an experimental investigation of the effect of void fraction content on the shear stress in a bubble flow in a vertical assembly of rods.

2. Experimental setup and measuring technique

The scheme of the experimental setup is shown in Fig. 1. From the pump I, the working fluid is fed into the square cross section channel 2. Nine rods are held in the channel, using three spacer grids.
A probe is mounted in the central one. The working channel cross-section diagram is shown in Fig. 2. Gas distributor 3 is located at the entrance of the working channel. The liquid flow rate is measured by an orifice meter 4. The gas flow rate is determined by the pressure drop on an orifice meter 5. In tank 7, phase separation occurs. Using a thermal stabilization system consisting of a heater 10, a valve 11, a coil 12, a thermocouple 13 and a regulator 14, the temperature of the liquid in the tank is kept equal to 22 ± 0.1 °C.

The local wall shear stress is measured using the electrodiffusion method. Determination of the flow hydrodynamic characteristics by this method is based on measuring the diffusion rate of active ions to the surface of the sensor-electrode, which depends on the gradient of the fluid flow rate on the probe surface. A special electrolyte consisting of an aqueous solution of potassium ferri- and ferrocyanide (K₃Fe(CN)₆ and K₄Fe(CN)₆) and sodium carbonate (Na₂CO₃) is used as a working fluid. The probe mounting scheme is shown in Fig. 3. The probe (a piece of platinum foil) is the cathode, and the assembly rod itself, in which the sensor is mounted, acts as the anode.

The relation between the local wall shear stress and the sensor current is as follows:

\[ \tau_w = AI^n, \]

where \( A \) and \( n \) are the calibration coefficients. The probe is calibrated before and after the main experiment in an annular channel in the same electrolyte.

The signal received from the electrodiffusion probe is amplified and transmitted to the ADC, after which the data are recorded using a personal computer into .txt files. The resulting data arrays are processed using software.

3. Experimental results

The experiment was performed at various gas flow rate ratios (\( \beta = 0, 3\%, 5\% \)). In this case, the superficial liquid velocity was equal to \( V_L = 0.69 \text{ m/s} \) which corresponds to the Reynolds number \( Re = 7500 (Re = \rho V_L D_h/\eta) \). The hydraulic diameter is defined as the ratio of the four cross section areas of the channel to its perimeter \( D_h = 4S/P = 9.7 \text{ mm} \). Gas flow rate ratio is determined as \( \beta = V_G/(V_G + V_L) \), where \( V_G \) is the superficial gas velocity. The measurements were carried out for different distances between the sensor and the spacer grid \( h \), also for two probe angle orientations (0° and 45°), as shown in Fig. 2.
Fig. 4 shows the measurements results of the local wall shear stress on the central assembly rod at different probe distances from the spacer grid. The ordinate shows the ratio of the wall shear stress in the bubble flow to wall shear stress in the single-phase flow $\frac{\tau_w}{\tau_0}$.

One can see that the gas phase has a significant effect on $\frac{\tau_w}{\tau_0}$. The effect of the gas phase on the shear stress increases with distance from the grid. Also near the grid the values of $\frac{\tau_w}{\tau_0}$ are larger for diagonal orientation of the probe. The unexpected result is that for $h/D_h \approx 18$, the graph assumes the maximum value and, with a further increase in the distance from the grid, $\frac{\tau_w}{\tau_0}$ decreases.
The dependence of the RMS value of wall shear stress fluctuation $\tau'_w/\tau_0$ on the distance to the grid is shown in Fig. 5. In a single-phase flow, the values of $\tau'_w/\tau_0$ decreases with increasing $h/D_h$ and reaches a constant value. Wall shear stress fluctuations in the bubbly flow near the grid behave similar to a single-phase flow, but at $h/D_h \approx 4$ they begin to increase sharply and reach a maximum at $h/D_h \approx 18$. This behavior is probably associated with the rearrangement of the distribution structure of the gas phase over the channel cross section at the distance from the grid [13].

Conclusions
The paper presents experimental data on the study of wall shear stress for bubbly flow in the square arrangement rods assembly. Experiments were performed by electrodiffusion method. It is shown that the adding of a gas phase into a stream has a significant effect on the fluid flow structure. The dependences of wall shear stress value and its fluctuations on the distance to the grid take a substantially nonmonotonic form, which radically differs from the single-phase flow. Experimental data obtained can be used to validate thermo hydraulic computer codes.

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