Heat transfer of a bubbly flow in a vertical rod bundle 3X3

M A Vorobyev and O N Kashinsky
Kutateladze Institute of Thermophysics, Novosibirsk, 630090, 1 Acad. Lavrentiev ave., Russia

E-mail: vorobyev@itp.nsc.ru

Abstract. This work aims at creating a reserve for increasing the efficiency of nuclear power plants. One of the main ways to intensify heat transfer in fuel assemblies is to increase the permissible mass concentration of the vapour phase. It is known that the introduction of a gas phase into a fluid flow leads to a modification of the flow structure and can significantly change the key thermal and hydraulic flow parameters, for example, the heat transfer coefficient. In this paper, we present the results of an experimental study of an ascending bubble flow in a vertical rods bundle 3X3. The working liquid was distilled water. The experiment was carried out at Reynolds numbers from 4000 to 11000 and gas flow rate ratios from 3 to 10%. As a result of the experiment, the heat transfer coefficients from the central rod heated by the electric current to the flow have been determined. It is shown that gas bubbles have the greatest effect on heat exchange at low Reynolds numbers and at a maximum distance from the spacer grid.

1. Introduction
Nowadays, two-phase gas-liquid flows represent one of the most intensively developing sections of mechanics and heat transfer of multiphase systems. Knowledge of information on the structure, averaged and pulsation characteristics of bubble flows is necessary for the design of modern power plants.

Foreign and domestic experts have compiled a vast experimental database of thermal and hydrodynamic characteristics of the flow of a single-phase coolant in vertical rods bundle. In the following works [1, 2] a conducted experimental study of the turbulent flow structure in the assembly of rods shows the effect of the assembly pitch on the exchange of mass and energy between the bundle cells. The article [3] provides a review of studies of pressure drop in rods bundles of various geometries. There have been also investigations of the influence of spacer and distancing grids on the flow structure [4, 5], and heat transfer coefficients [6, 7]. A great amount of experimental works give reliable verification of theoretical and numerical studies [8, 9].

In certain modes of operation of nuclear power plants, as well as in emergency situations associated with a drop in the flow rate of coolant, boiling may occur. It is shown in [10-12] that the presence of bubbles in the liquid flow leads to a change in the key thermal-hydraulic flow characteristics, such as hydraulic resistance or heat transfer coefficients. Thus, the relevance of bubbly flows studies in channels simulating rod bundles is caused by safety issues. In the literature there are many works devoted to this topic [13-15]. But these papers mainly focus on determining the local gas content and the rate of gas inclusions, as well as the influence of spacer grids on these parameters. At the same
time heat exchange between a two-phase bubbly flow and a fuel rod in rods bundle is not enlightened in the literature.

The aim of this work is an experimental study of the effect of gas flow rate on heat transfer in a bubbly flow in the vertical assembly of rods 3X3.

2. Experiment facility and technique

A schematic diagram of the experimental setup is shown in figure 1. From pump 1, the working fluid was supplied to channel 2, which is a 40-mm-thick Plexiglas tube with square cross section. In the channel, 9.1 mm diameter rods were positioned by means of three spacer grids. The central rod is a thin-walled stainless steel tube into which the sensor was mounted. At the bottom of the channel there was a gas distributor 3, generating bubbles. The liquid flow rate was determined by the pressure drop on the diaphragm 4. The pressure drop was measured by a differential pressure transducer. The gas flow rate was also determined from the pressure drop across the diaphragm 5. The gas-liquid mixture from the outlet of the working channel through the flexible plastic pipe 6 was supplied to the separator tank 7 where the phases were separated. Then the liquid was drained into the main tank 8 via the return pipe 9. Using a thermo 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 was kept constant at 22 ± 0.1°C. To monitor the temperature of the liquid at the inlet to the test channel, a resistance thermometer 15 was mounted in the pipe.

The working liquid was distilled water. The experiments were carried out at liquid flow rate \( V_L \) from 0.4 to 1 m/s, which corresponds to Reynolds numbers \( Re = 4000 - 11000 \) (\( Re = \frac{\rho V_L D}{\eta} \)). The hydraulic diameter was defined as the ratio of the four cross-sectional areas of the channel to its perimeter \( D = \frac{4S}{P} = 9.7 \) mm. The gas flow rate ratio \( \beta \) was determined as \( \beta = \frac{V_G}{V_G + V_L} \), where \( V_G \) is the gas flow rate. During the experiments the gas flow rate ratio varied within 3–10%.

To study the heat transfer the authors used the thin-walled stainless steel tube section to the inner surface of which a miniature platinum resistive temperature sensor was pressed tightly. The tube can be moved up and down, changing the distance from the sensor to the spacer grid downstream. By means of copper pipes an electrical current was applied to the site. Knowing the current power supplied to the heating section and the wall temperature, one can find the heat transfer coefficient \( \alpha = \frac{q}{\Delta T} \), where \( \Delta T = 10^\circ C \) is the temperature difference of the heated tube wall and the flowing fluid flow. The heat flux density is calculated as \( q = \frac{F R}{s} \), where \( R \) is the electric resistance of the stainless steel tube, \( s \) is its area, and \( I \) is the electric current flowing through the heating section. A similar technique.
was applied in [16, 17] for studying heat transfer in a gas-liquid flow in an inclined channel. The Nusselt number was defined as $Nu = \alpha \cdot D_g / \lambda$, where $\lambda$ is the thermal conductivity of water.

3. Experimental results

Figure 2 a shows the measurement results of the heat exchange as a function of the Reynolds number for various values of $\beta$. The temperature sensor was 250 mm above the spacer grid. It can be seen that the gas phase has the greatest effect on heat exchange at low Reynolds numbers and this effect increases substantially with increasing gas flow rate.

Figure 3 b shows a similar graph, but for the case when the sensor was 60 mm above the spacing grid. It can be seen that the influence of the spacer grid on the intensification of heat transfer is overwhelming, in comparison with the effect of gas addition.

The dependence of the dimensionless heat transfer coefficient on the distance to the spacer grid is shown in figure 4. It can be seen that with increasing distance from the grid the contribution of bubbles to the intensification of heat transfer becomes higher.

4. Conclusions

The paper presents experimental data on the study of heat transfer in an upward bubbly flow in an assembly of vertically located rods 3x3. In the experiments, a significant effect of the gas phase on heat exchange was observed. An increase in the influence of the gas phase on heat exchange is shown with a decrease in the Reynolds number, a removal of the investigated region from the spacer grid and an increase in the fraction of the gas phase. The given experimental data can be used for validation of calculation codes.
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