NUMERICAL SIMULATION OF NON-UNIFORM VOID FRACTION TRANVERSAL PROFILES ON HYDRODYNAMICS AND HEAT TRANSFER CHARACTERISTICS FOR UPWARD AND DOWNWARD TURBULENT TWO-PHASE BUBBLY FLOW

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1 Introduction

Knowledge of complicated two-phase flow structure is of vital importance in such different fields as petroleum, chemical and thermal engineering. Especially nuclear reactor safety issues require comprehensive understanding of important features of two-phase flows under various conditions. The recent experimental investigations into local characteristics of non-equilibrium bubbly flows have revealed that, in particular, the effects of anomalous wall shear stresses increase under the conditions of predominantly near-wall concentration of gas (or vapor) phase of low velocity forced flows.

The one-dimensional empirical and semi-empirical methods that are employed in practical applications often failed to predict these effects properly. It was due primarily to the fact that these models do not take into account the real three dimensional flow structures. For example, these models suffer neglect of the bubble disturbing effect on the momentum transfer as well as incomplete description of inherent turbulent two-phase flow motion. Although analytical tools on the basis of the different variants of multi-dimensional two-fluid model are in progress in many research centers, they are somewhat far from being complete.

It is known that successful attempts have been made to calculate such flow velocity profiles on the basis of Prandtl-type model taking into account the wall turbulence and the "bubble" agitation action with a radial profile of the void fraction being known. However they are valid only for the stabilized flow without any disturbing factors. Formulation of and solution to such problems on the basis Reynolds-type equation in two-dimensional form are of significant scientific and practical interest.

In this paper we propose an approach on the basis of the Reynolds-stress model providing more detailed description of the stress components that are conisdered responsible for the phase distribution and anomalous friction effect enhancement.

2. Mathematical model

For an axially symmetrical two-phase flow, we use the time average Reynolds-type equations for the liquid-phase taking into account the Bussinesq's hypothesis between stress tensor and strain velocity tensor. The Reynolds equations don't take into account for interface momentum transfer term.

Two-phase flow density is a sum of the relevant phase densities with a known radial void fraction profile from experiment. We assume that turbulent viscosity is subdivided into two components: one due to the inherent liquid turbulence independent of relative motion of bubbles and the other due to the additional turbulence caused by bubble agitation. For the liquid turbulence we used the Reichardt relationship. The additional turbulent viscosity due to relative motion of gas bubbles is given in proportion to a void fraction, a bubble diameter, and velocity of relative motion.

3. Numerical method

Implicit numerical method has been developed to solve equations of the mathematical model. Discretization of governing equations is carried out on the base of monotonous balance neutral (MBN) difference scheme that allows preserving important integral properties of differential operators. Computational grids are irregular, which yield good precision for description of the thin boundary layers, and calculations can be performed up to solid boundaries. A difference equation for pressure is derived from the difference equations of continuity and momentum. The discrete equations obtained are non-linear, so linearization is introduced and implicit iterative procedure is developed for yielding convergent solutions. Special attention is paid to the explicit incomplete factorization method, which is employed for solving linearized momentum and pressure difference equations. This method is realized in the code named FLUID2D.

4. Discussion of numerical predictions and comparison with experimental data

The FLUID2D code is used for hydrodynamic study of two-component (air-water) up- and downward flow experiments. The purpose of numerical investigations is to validate the proposed models and 2-D calculations of the velocity and pressure fields, and shear stress with known radial void fraction profiles. The grid system with Nr x Nz = 60 x 200 is employed. For a correct shear stress description, we use a highly irregular grid system with logarithmic compressibility to the wall, so that the first step near the wall is equal to 10^{-5}m. The input data for the FLUID2D code include experimental void fraction profiles, and bubble diameters.

Testing the FLUID2D code for a single-phase flow has shown good agreement between calculation and experiment for the velocity profile, and average and local friction factors with different Reynolds numbers at the inlet.

The experimental data and calculation results have revealed appreciable enhancement of the wall shear stresses for two-phase upward flow and less appreciable enhancement for downward flow. As a whole, it is noted that rather satisfactory agreement between experiment and calculation with respect to both velocity profiles and shear stresses.

5. Conclusions

The general Reynolds-type momentum model has been implemented in the FLUID2D code and applied in predicting the liquid velocity profile and shear stress behavior for turbulent up-ward and down-ward two-phase flow, where we have assumed the “saddle”-shape void fraction profile and Sato et al hypothesis for gas-liquid phase turbulence. The numerical method allows conducting calculations up to the rigid wall including laminar layer and provides correct shear stresses in the frame of mathematical model to be considered. Numerical results are in satisfactory agreement with experimental data in a wide range of flow regime, including anomalous wall shear stress enhancement. This approach has considerable possibilities in improving turbulence models and numerical predictions in many two-phase flow problems.