Prediction of the Void Coring Phenomena in a Triangular Conduit

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1. Introduction

The phase distribution in any two-phase flow system is one of the most important parameters for an accurate analysis of the momentum and heat transfer mechanisms. A multidimensional analysis of an accurate flow and void distribution can result in an accurate prediction of such important thermal-hydraulic phenomena as the local critical heat flux. However, numerous experimental and analytical studies of a two-phase flow in the past were not able to satisfactorily predict the lateral phase distribution in a wide range of conditions due to the uncertainties associated with the interfacial constitutive models and the turbulence models.

The previous study[1] could not predict the void coring for the upward two-phase flow observed in the experiment[2]. Recently, Tomiyama *et al.*[3] showed that there is a critical bubble diameter causing the radial void profile transition from a wall peaking to a core peaking in an air-water bubbly flow. Using the transverse lift coefficient proposed by Tomiyama *et al.*, this study simulated the void coring phenomena of the air-water flow in a triangular conduit and compared the predicted void distributions with the measurements.

2. Mathematical Models

2.1 Two-Fluid Model

The ensemble-averaged conservation equations of the mass and momentum for each phase can be written as

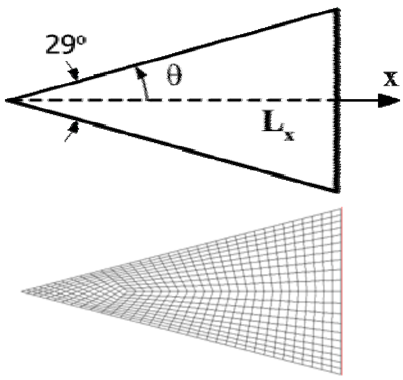

Figure 1. Cross section of a triangular conduit and the plane mesh.

$$\frac{\partial}{\partial t}(\alpha_k \rho_k) + \nabla \bullet \left(\alpha_k \rho_k \vec{U}_k\right) = 0 \qquad (1)$$

$$\frac{\partial}{\partial t}\left(\alpha_k \rho_k \vec{U}_k\right) + \nabla \bullet \left(\alpha_k \rho_k \vec{U}_k \vec{U}_k\right) = \nabla \bullet \left[\alpha_k \mu_k^e \left(\nabla \vec{U}_k + \left(\nabla \vec{U}_k\right)^T\right)\right] - \alpha_k \nabla p_k + \alpha_k \rho_k g + M_k \qquad (2)$$

where α_k, ρ_k, p_k, μ_k^e and $\vec{U}_k$ are the volume fraction, density, pressure, effective viscosity and the velocity of phase *k*, respectively. M_k is the rate of the momentum transfer per unit volume at the interface.

2.2 Closure Laws

The interfacial momentum transfer term is expressed as a superposition of the terms representing different physical mechanisms, i.e.,

$$M_k = M_k^d + M_k^{vm} + M_k^L + M_k^{LW} + M_k^{TD} \,. \qquad (3)$$

The individual terms on the right hand side of eq. (3) are the drag force, virtual mass force, lift force, wall lubrication force and the turbulent dispersion force, respectively. Details on the interfacial momentum transfer terms and the bubble turbulence are given in the previous study.

In particular, the lift force is expressed as

$$M_G^L = -M_L^L = C_L \alpha_G \rho_L \left(\overline{U}_G - \overline{U}_L\right) \times \left(\nabla \times \overline{U}_L\right) \,. \qquad (4)$$

Here, C_L is the lift force coefficient which depends on the bubble diameter. It takes positive values for small bubbles, whereas it takes negative values for large bubbles[3]. Hence, it was set to –0.02 and/or –0.01 with the bubble diameter of 5.9 mm in this study.

3. Numerical Method

This study simulated the experiment of an air/water two-phase flow in a triangular conduit. The triangle height and base are 98.4mm and 50.8mm, respectively. The apex angle is 29^o. Figure 1 shows the cross sectional view of the triangular conduit and the computational mesh.

Uniform distributions of the velocity and phase are assumed at the inlet and a constant pressure is assumed at the exit of the conduit. A no slip condition for the liquid phase and a free slip condition for the gas phase are used at the walls.

A commercial CFD code CFX-5.7 was used to predict the phase distribution of the turbulent air-water bubbly flow. The dispersed phase is characterized by a single mean diameter. The calculations were performed at the superficial air velocities(j_G) of 0.018 m/s and 0.035 m/s for the superficial water velocities(j_L) of 0.17 m/s and 0.34 m/s, respectively.

4. Results

Figure 2 compares the lateral distributions of the void fraction at j_L=0.34 m/s and j_G=0.035 m/s. Unlike the previous study, the present prediction shows a higher void fraction in core region which agrees with the measured one well. This is because this calculation used the negative lift coefficient(C_L=-0.02) with the large bubble diameter based on the proposal by Tomiyama et al.[3]. Figure 3 illustrates the cross-sectional void distribution which clearly shows the void coring phenomena.

Figure 4 also shows the comparison of the void distributions for j_L=0.17 m/s and j_G=0.018 m/s. The prediction with C_L=-0.02 overpredicted the void coring, i.e., a higher void fraction in the core region. It shows a somewhat less over-prediction with a smaller negative lift coefficient(C_L=-0.01). This implies that the lift force for the bubbles to migrate towards the core region decreases as the relative gas flow rate increases.

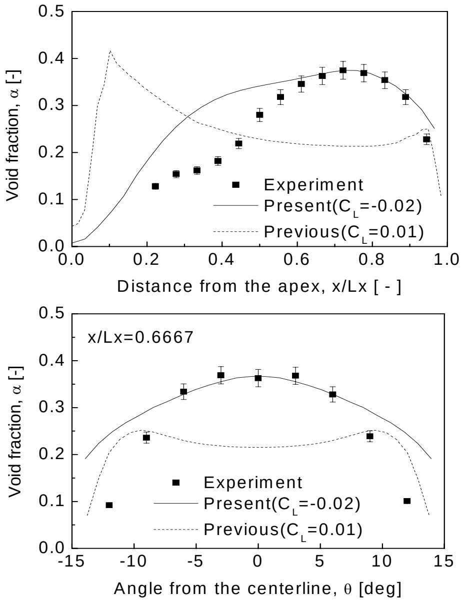

Figure 2. Comparisons of the predicted and measured local void fraction at j_L=0.34 m/s and j_G=0.035 m/s.

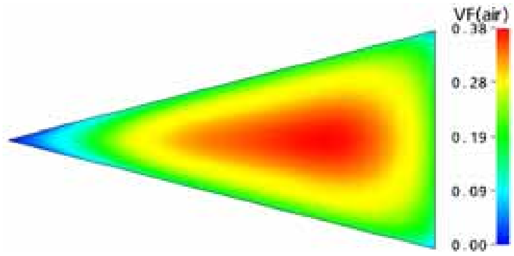

Figure 3. Planar void distribution predicted at j_L=0.34 m/s and j_G=0.035 m/s.

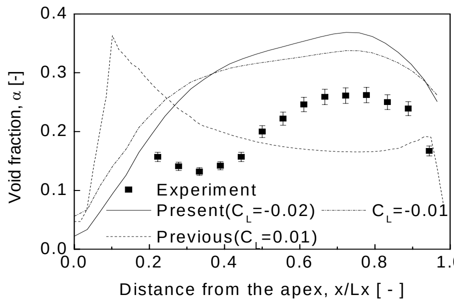

Figure 4. Comparison of the predicted and measured local void fraction along the centerline for j_L=0.17 m/s and j_G=0.018 m/s.

5. Conclusion

The air-water bubbly flow in a triangular conduit was simulated using a new correlation for the lift-force coefficient which depends on the bubble diameter. The negative value of the lift coefficient is successful in capturing the void coring phenomena occurring in the upward bubbly flow with large bubbles. It is however still necessary to improve the closure laws for a more accurate prediction in the wide range of the two-phase flow conditions.

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