Prediction of the Phase Distribution in a Triangular Conduit

W. K. In,[a] D. H. Hwang,[a] C. H. Shin,[a] D. S. Oh,[a] T. H. Chun [a]

[a] Korea Atomic Energy Research Institute, P. O. Box 105, Yuseong, Daejeon, Korea, 305-600, wkin@kaeri.re.kr

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 (CHF). 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.

There have been some numerical works to predict the phase distribution in two-phase bubbly flows. They predicted well the void peak near the wall for an up flow and the void coring for a down flow. However, there are few studies available on the void coring for an up flow. This study simulates the air/water measurements of a phase distribution in a triangular conduit [1] which shows the void coring phenomena.

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

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

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

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

$$M_k=M_k^d+M_k^{vm}+M_k^L+M_k^{LW}+M_k^{TD}. \tag{3}$$

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.

The assumption to model the two-phase bubbly flow turbulence in the liquid phase is that the shear-induced turbulence and the bubble-induced turbulence can be superimposed linearly. Hence, the turbulent viscosity of the liquid phase can be expressed as

$$\mu_L^t=\mu_L^{t(SI)}+\mu_L^{t(BI)}. \tag{4}$$

The shear-induced turbulent viscosity is determined from the standard $k-\varepsilon$ model and the bubble-induced turbulent viscosity is obtained from the correlation. The effective viscosity of the liquid phase (μ_L^e) can be written as a sum of the molecular viscosity and the turbulent viscosity.

Details on the interfacial momentum transfer terms and the bubble turbulence are given in a previous study [2]. The values of the closure coefficients used in this study are

$$\begin{aligned}&C_D=\frac{24}{\mathrm{Re}}\left(1+0.1\mathrm{Re}^{0.75}\right),C_{vm}=0.0,C_L=0.01,\\&C_1=-0.01,C_2=0.025,C_{TD}=0.1,C_{tb}=1.2\end{aligned}. \tag{5}$$

3. Numerical Method

This study simulated the experiment of an air/water two-phase flow in a triangular conduit [1]. The triangle height and base are 98.4mm and 50.8mm, respectively. The apex angle is 29°. 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 pipe and the subchannel. A no slip condition for the liquid phase and a free slip condition for the gas phase are used at the walls.

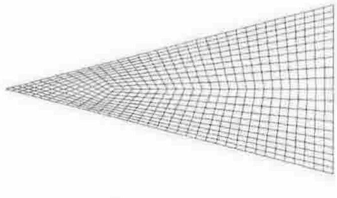


Figure 1. Cross section of a triangular conduit and the plane mesh.

A commercial CFD code CFX-4.4 was used to predict the three-dimensional phase distribution of the turbulent air/water bubbly flow. The dispersed phase is characterized by both a single mean diameter and multiple-size-group(MUSIG). The liquid mass flow rate is 1.682 kg/s and the quality is 0.257%.

4. Results

Figure 2 shows the lateral distributions of the predicted and measured local void fraction and the liquid velocity at X=6/9Lx. The prediction by the PHOENICS code [3] is also used for a comparison. The experimental results show the void coring, i.e., a higher void fraction in the core region but the PHOENICS code predicts the void peak near the wall. CFX-4 shows very flat profiles for the void fraction of both a single mean diameter(Db=3mm) and the MUSIG model. CFX-4 and PHOENICS predicts the velocity distribution flatter than the measured one.

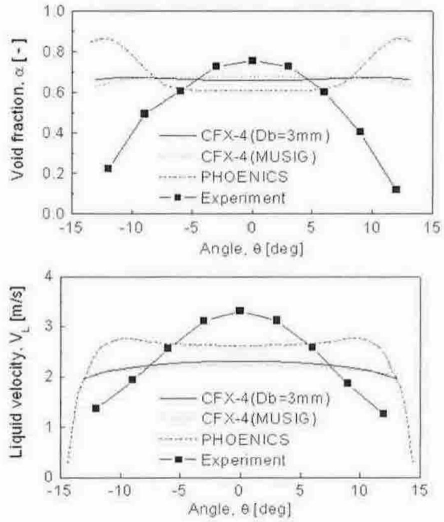
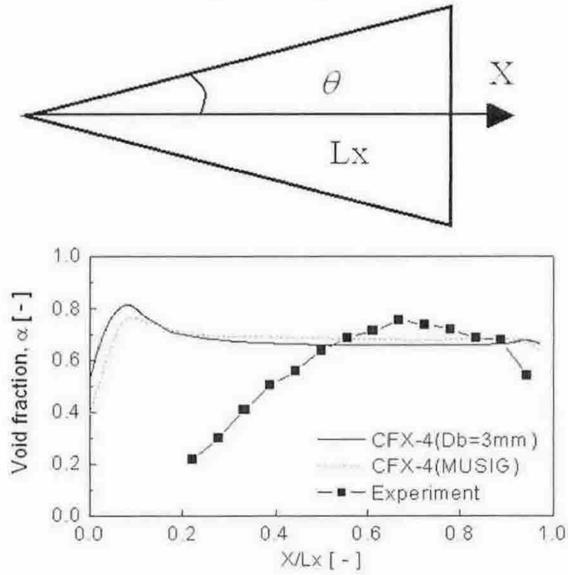


Figure 2. Comparison of the predicted and measured local void fraction and the liquid velocity at X=6/9Lx.



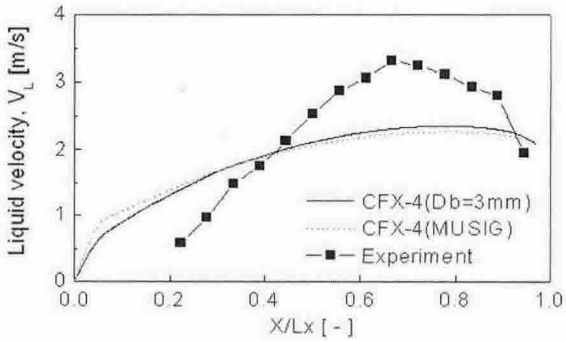


Figure 3. Comparison of the predicted and measured local void fraction and the liquid velocity along the perpendicular through the apex.

Figure 3 compares the lateral profiles of the local void fraction and the liquid velocity along the perpendicular through the apex. CFX-4 predicts very high void fraction in the apex region while the measured data shows the concentration of vapor(air) in the largest flow region.

5. Conclusion

The air/water two-phase flow in a triangular conduit is simulated using the CFD code, CFX-4.4. Although the current CFD simulation showed its applicability for complex three-dimensional two-phase flows, it could not predict the void coring for the up flow observed in the experiment. Hence, some improvements in the constitutive modeling are required to more accurately predict the phase distribution in two-phase flow systems.

Acknowledgement

The authors express his appreciation to the Ministry of Science and Technology (MOST) of Korea for financial support.

REFERENCES

[1] S. Sim, R. T. Lahey Jr., The Measurements of Phase Distribution Phenomena in a Triangular Conduit, NUREG/CR-3576, December, 1983.

[2] W. K. In, T. H. Chun, CFD Simulations of Two-Phase Bubbly Flows in a Circular Channel and a Rod Bundle Subchannel, Proceedings of the International Conference on Nuclear Engineering(ICONE-9), Apr.8-12, 2001, Nice, France.

[3] R. T. Lahey Jr., T. G. Theofanous, and W. H. Amarasooriya, Multiphase Science and Technology, Vol. 6, Data Set No. 4, pp.15-21, 1992.