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Validation of the CUPID code for the Natural Circulation in a Small Scale Pool

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1. Introduction

A three–dimensional thermal-hydraulic code, CUPID [1], has been developed for the component scale analysis of a nuclear reactor. The CUPID code has been used for the analysis of the PASCAL (PAFS Condensing Heat Removal Assessment Loop) test. The PAFS is one of the safety features of the APR+ (Advanced Power Reactor +), which is intended to completely replace the conventional active feedwater system. However, the PASCAL test does not give the velocity field information so that a small scale pool test was performed to investigate the velocity and temperature in a pool. In this research, the velocity field of the small scale pool in single- and two-phase natural circulation is calculated, and the CUPID code is validated qualitatively.

2. Small Scale Pool

Fig. 1 shows the schematic diagram of the small scale pool. The pool has 0.3 m width, 0.5 m height, and 0.06 m depth. Water fills the pool up to 0.4 m height. A heater rod of 0.15 m length is located 0.1 m height from the bottom. To estimate the velocity, PIV (Particle Image Velocimetry) is used. The heat is 600 kW and the initial temperature of water is 300.15 K.

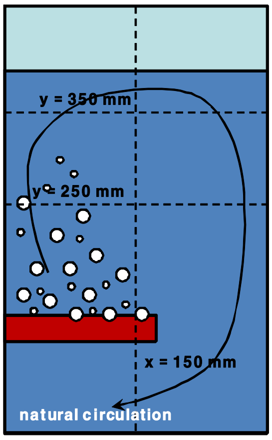

Fig. 1. Schematic diagram of a small scale pool.

Water is at rest initially. When the heat is imposed, the density difference of the water around the heater causes buoyancy so that the natural circulation occurs.

3. Analysis using the CUPID Code

3.1 Initial Set-ups

The analyses are performed in two dimensions. Fig. 2 shows the grid generation of the small scale pool. The heater rod is approximated using the porous medium.

The domain is divided into 30x45. The temperature of the air and water is initially 300.15 K. The upper region is filled with dry air and has 1 atm in pressure. The gas void fraction is 1.0 in the air part and 0.0 in the water part.

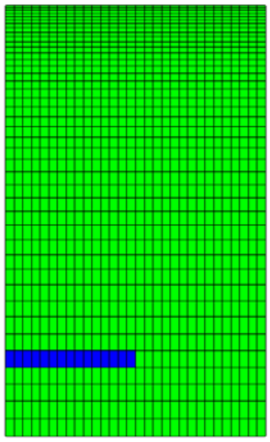

Fig. 2. Grid generation of the small scale pool using porous medium.

The Noto & Matsumoto's zero equation model[2] is used for the turbulence analysis. For the bubble departure, Fritz model[3] is applied. The bubble diameter for the interfacial heat transfer and interfacial drag is obtained from the Hibiki model[4]. Moreover, because this pool test includes the various flow patterns such as bubbly, mist, and stratified flow, the interphase topology map[5] is adopted. Except for the three representative patterns above, the other flow patterns are interpolated linearly. In this calculation, an additional diffusion term is included to control the non-physical behaviors in the stratified region. Finally, to compensate the wall drag effect of the experiment due to the finite depth of the rig, the Darcy's formulation is used for the two-dimensional calculations.

3.2 Results for Single-Phase Natural Circulation

Fig. 3 presents the velocity distribution from the experiment and the CUPID code when the pool temperature reached up to 60.5 ℃. The u-velocity along the x-axis and the v-velocity along the y-axes are agreed well with each other. However, as shown in Fig. 3, the u-velocity below the heater which is located at 100 mm height is quite different. This means that the region below the heater rod does not get involved in the natural circulation.

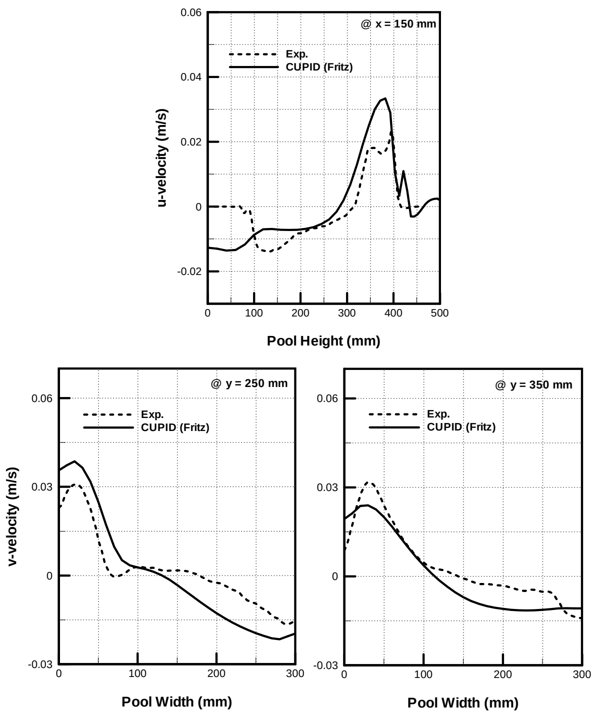

Fig. 3. u- and v-velocity distribution in two-dimensional calculation for the single phase natural circulation condition.

To depict the thermal stratification below the heater rod, two parameters such as the three-dimensional effect and the laminar effect, are considered in Fig. 4. As shown in Fig. 4, the three-dimensional effect causes the thermal stratification. When the three-dimensional test is corrected with the laminar assumption, the result approaches to the experimental result a lot more.

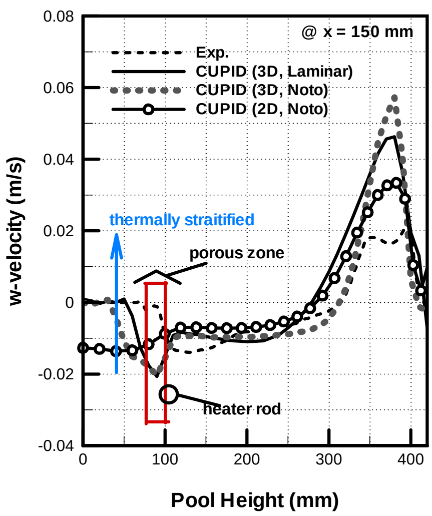

Fig. 4. Improved u-velocity distribution for the single phase natural circulation condition.

3.3 Results for Two-Phase Natural Circulation

Fig. 5 shows the two-phase natural circulations in two dimensions. When the pool temperature rises up to the saturation condition, the velocity increases abruptly. Because of the momentum increase, the thermal stratification has been disappeared. The analysis results show a good agreement with the experimental data.

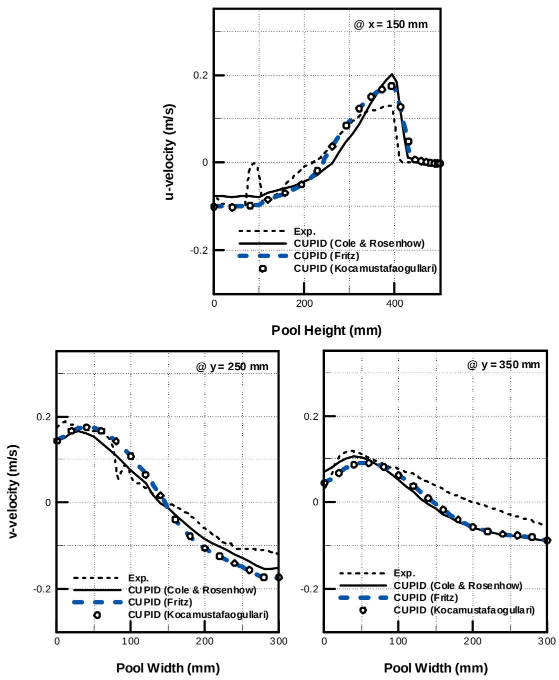

Fig. 5. u- and v-velocity distribution in two-dimensional calculation for the two phase natural circulation condition.

3. Conclusions

The analyses of the natural circulation in a pool are validated with the small scale pool experiment. The single- and two-phase natural circulation velocities are compared qualitatively. Because of the experimental condition which is at rest initially, the thermal stratification is observed and simulated successively in the single-phase condition. For the two-phase condition, the abrupt momentum increase is captured successively. The velocity distribution in two-phase natural circulation are agree well with the experiment.

REFERENCES

[1] J. J. Jeong, H. Y. Yoon, I. K. Park, H. K. Cho, and H. D. Lee, Development and Preliminary Assessment of a Three-Dimensional Thermal Hydraulics Code, CUPID, NET, Vol.42, No.3, p.279, 2010.

[2] K. Noto and R. Matsumoto, Turbulent Heat Transfer by Natural Convection along an Isothermal Vertical Flat Surface, Trans. ASME J. Heat Transfer, 97, p.621-624, 1975.

[3] W. Fritz, Maximum Volume of Vaper Bubbles, Phys. Z., 36, p.379-384, 1935.

[4] T. Hibiki, T.H. Lee, J.Y. Lee, and M. Ishii, Interfacial Area Concentration in Boiling Bubbly Flow Systems, Chemical Engineering Science, 61, p.7979-7990, 2006.

[5] Tentner et al., Computational Fluid Dynamics Modeling of Two-Phase Flow Topologies in a Boiling Water Reactor Fuel Assembly, Proc. Of ICONE19, Orlando, USA, May, 2008.