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Investigation of the Heat Exchanger Bundle Effect for the Passive Condensate Cooling Tank Using the CUPID Code

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1. Introduction

The need for a multi-dimensional analysis of transient thermal hydraulic phenomena in a component of a nuclear reactor is increasing with the advanced design features. Motivated by this, the development of a new thermal-hydraulic analysis code, named CUPID [1], is in progress at KAERI (Korea Atomic Energy Research Institute). The simulation of the passive secondary cooling system, PAFS (Passive Auxiliary Feedwater System) has been considered as one of the practical applications of CUPID. In order to validate the two-phase flow models of CUPID, the PASCAL test facility was simulated with a porous media model in our previous study [2]. In the present study, the heat exchanger bundle effect on the natural circulation heat transfer was investigated using CUPID for the passive condensate cooling tank (PCCT) of the PAFS. The calculation results with the porous media model, such as the liquid temperature and velocity, were imposed as boundary conditions of the detailed flow simulation near the single heat exchanger tube of the PASCAL facility. Thereafter, the bundle effect was investigated by comparing the calculation result of the unit cell of the PAFS tube bundle and that of the single tube. This paper presents the two-dimensional porous media analysis result for the PCCT of the PASCAL facility, two-dimensional open media analysis result for a single heat exchanger tube, and two-dimensional open media analysis result for the unit cell of the heat exchanger bundle.

2. PCCT Simulation Result

A transient calculation was performed in order to verify whether the CUPID code can reproduce the natural circulation and the boil-off phenomena in the PCCT. The problem time was 30,000 seconds same with the experiment. Figure 1 shows the void fraction distribution change from 0 to 30,000 seconds. As the water temperature increased, the water level was elevated from 9.8 m to 10.4 m owing to a swelling. For initial 7,000 seconds, the single phase natural circulation was continued because the liquid subcooling had been maintained. After 7,050 seconds, a two-phase region appeared near the free surface. It should be noted that this phase change was induced by a flashing of the water. After the flashing, the water temperature dropped to the saturation temperature and then, it flowed downward along the right side wall and the two-phase natural circulation was established. Fig. 2 shows the liquid temperature and the water level comparison results between the calculation and the experiment and it was concluded that the models and the constitutive relations implemented for this simulation can be applied for the analysis of the PASCAL facility.

3. Single Heat Exchanger Tube Simulation

As the second step of the analysis, the single heat exchanger tube that the PASCAL facility was included was analyzed by CUPID. The liquid temperature, velocity and pressure obtained from the PCCT simulation was imposed for the inlet and outlet boundary conditions of this analysis. Fig. 3 shows the computational domain. A cross-section along the depth direction at a location was modeled in two-dimension, where the bending part of the heat exchanger starts. Total 6933 polygonal meshes were used for the analysis. Figure 4 shows the calculation results of the void fraction, the liquid temperature, and liquid velocity distributions. The calculated heat exchanger wall temperature is compared with the experimental result as well. These show that the CUPID can reproduce the two-phase phenomena near a single heat exchanger tube reasonably well.

4. Unit cell of the Tube Bundle Simulation

A similar approach with the above analysis was applied to the unit cell of the heat exchanger tube bundle. Figure 5 shows the arrangement of the heat exchanger tube bundle. Since they are not uniformly arranged in terms of space, the local volumetric heat source in the tube bundle is larger than that in the PASCAL facility. It is required to verify that the distortion of the local power does not cause a significant distortion of the heat exchanger wall temperature in order to ensure that the cooling capability of the heat exchanger evaluated by the PASCAL facility is applicable to the bundle geometry. For this reason, the unit cell of the tube bundle was simulated with a periodic boundary condition on the side boundaries and a total of 15282 polygonal meshes were used. The same flow conditions were imposed on the boundaries and this includes conservativeness because the natural circulation rate would be higher in the bundle case due to the higher local volumetric power. Figure 6 shows the calculation results of the void fraction and the liquid temperature. Compared to the single tube calculation, a higher void fraction was obtained with the higher volumetric power. The maximum void fractions on the heat exchanger tube were 0.43 and 0.78 at the single tube and bundle calculations, respectively. However, the subcooled boiling flow patterns were maintained in the bundle case, and therefore, the maximum temperatures of the liquid and the heat exchanger surface were comparable with the single tube calculation results. This implies that the cooling capability of the heat exchanger tube bundle by the natural circulation is comparable with that in the PASCAL facility.

5. Conclusion

The two-phase flow phenomena nearby the heat exchanger tube were analyzed by the CUPID code in order to investigate the effect of the tube bundle compared to the single tube. The calculation result showed that the heat exchanger tube temperature in the unit cell of the bundle is expected comparable to that in the single tube geometry even if a higher void fraction appears in the former one. Considering the conservativeness of the imposed boundary conditions, a better cooling capability is expected for the bundle geometry in more realistic simulation.

Acknowledgments

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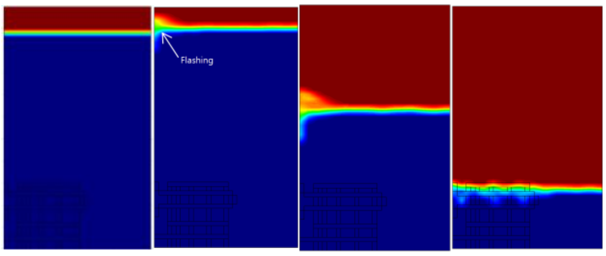

Fig. 1. Void fraction distribution in the PCCT

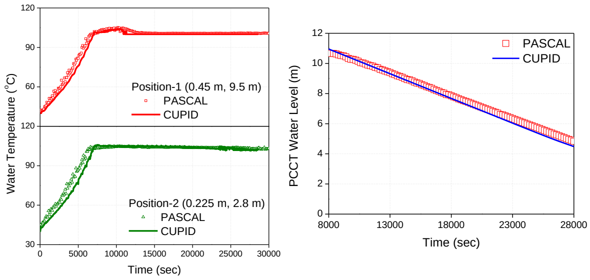

Fig. 2. PCCT analysis result

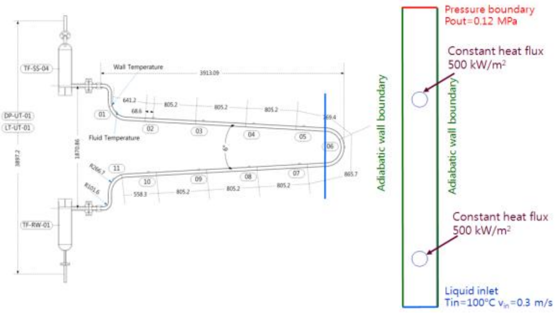

Fig. 3. Computational domain

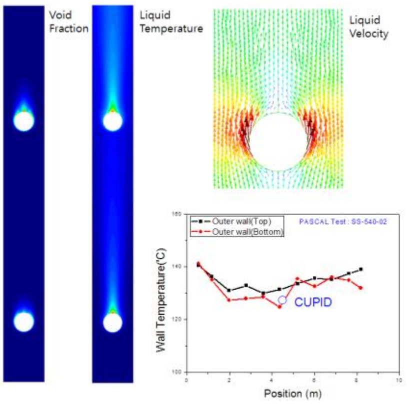

Fig. 4. Calculation result (single tube)

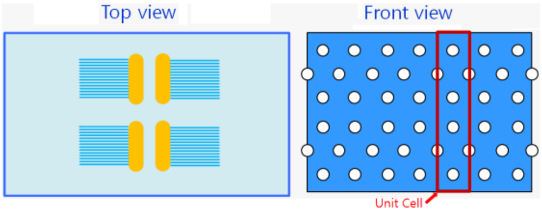

Fig. 5. Arrangement of the tube bundle (simplified)

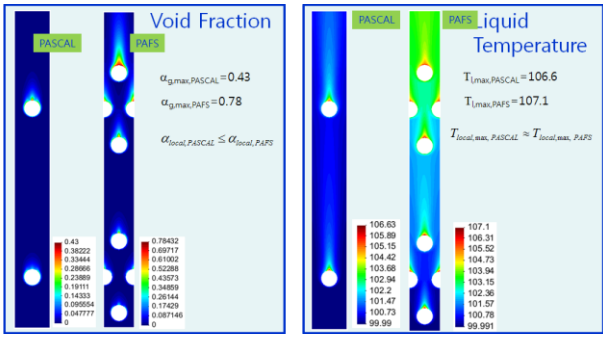

Fig. 6. Calculation result (single tube vs. unit cell)