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Application of the CUPID Code for the Simulation of Multi-dimensional Thermal Hydraulic Phenomena in Advanced Power Reactors

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1. Introduction

A multi-dimensional thermal hydraulic analysis code, CUPID (Component Unstructured Program for Interfacial Dynamics), is being developed for the analyses of components of a nuclear reactor, such as reactor vessel, steam generator, containment, etc. In this study, the CUPID code was applied for the simulation of the multi-dimensional phenomena that can occur in advanced power reactors such as APR1400 and APR+. The simulations of the following phenomena were attempted with simplified geometries and two-phase models; the falling ECC (Emergency Core Coolant) film and the ECC bypass in the DVI (Direct Vessel Injection) system downcomer and the steam condensation inside the heat exchanger of PAFS (Passive Auxiliary Feedwater System). This paper presents the preliminary simulation results.

2. Falling ECC film in the downcomer

It was reported that the spreading width of a falling liquid film on the downcomer wall in the DVI system has a strong influence on the bypass of ECC during the reflood phase of LBLOCA (Large Break Loss of Coolant Accident) [1]. However, due to its multi-dimensional characteristic, the liquid film is not supposed to be reproduced by the one-dimensional thermal hydraulic codes. In this study, in a bid to verify the applicability of the CUPID code to the liquid film, the DIVA (1/5 length scale) test, was simulated. Figure 1 shows the calculation result of void fraction. The liquid injection velocity at the DVI nozzle was 1.9 m/s. The DVI nozzle in the calculation was simplified to a rectangular channel that has the same flow area with that of the test facility. As presented in Fig. 1, the parabolic shaped liquid film was reasonably well reproduced by the calculation. The predicted liquid film width was compared with the experimental data in Fig. 2. In the calculation, the void fraction value 0.98 was used to define the edge of the liquid film. The comparison result showed that the liquid film width on the downcomer wall can be well captured by the CUPID code.

3. Direct ECC bypass

The direct ECC bypass can occur in the DVI system downcomer by the interaction between a falling liquid film and a transverse steam flow. Since it is a major bypass mechanism of the ECC during the reflood phase, it is considered as an important safety issue of an advanced power reactor with the DVI system. The bypass phenomena was simulated using the CUPID code with a simplified downcomer geometry as shown in Fig. 3 and the predicted void fraction is illustrated in Fig. 4. The steam velocity was 30 m/s at each inlet and the liquid injection velocity was 2.0 m/s at the DVI nozzle. The system pressure was 0.1013 MPa at the exit. Consistent with the experimental observation result [1], the width of the downward liquid film became narrower as it fell down along the downcomer wall due to the interfacial shear force by the transverse steam flow. Then, the liquid film was taken off toward the broken cold leg, thereby bypassed out. From this preliminary calculation, it was verified that this mechanism can be reproduced by the CUPID code qualitatively well.

4. Steam condensation in the PAFS Heat Exchanger

APR+ (Advanced Power Reactor Plus) adopts PAFS (Passive Auxiliary Feedwater System) on the secondary system [2]. It cools down the secondary system of a nuclear power reactor by heat transfer at a horizontal U-tube in PCCT (Passive Condensate Cooling Tank). High pressure steam flow from the steam generator is condensed in the horizontal heat exchanger inclined by 3 degrees as shown in Fig. 5. In the present study, the steam condensation phenomenon inside a slightly inclined tube was simulated using CUPID in two-dimension. Figure 6 presents the computational domain and the boundary conditions of the simulation. The steam inlet velocity was 6.6 m/s and the outlet pressure was maintained at 7.4 MPa. Instead of simulating the PCCT where a pool boiling occurs, a constant temperature boundary condition was imposed on the tube wall and the saturation temperature at 0.2 MPa was applied. Figure 7 shows the void fraction distribution at three different locations; near the inlet, at the U-bend and near the outlet. The steam condensation started after the first bend and the void fraction gradually decreased on the wall. At the U-bend, due to the centrifugal force, most of the liquid existed on the outer wall of the bend and then, the thickness of the liquid layer increased along the length. Finally, the stratified flow appeared near the last bend, which has pure liquid at the bottom of the tube and pure steam at the top. This result showed that CUPID can be applied to the simulation of the PAFS heat exchanger analysis if it employs a proper steam condensation model and a heat partitioning model on the cold wall.

5. Conclusion

The CUPID code simulations for the multi-dimensional two-phase flow phenomena in the advanced power reactors were attempted in the present paper. The preliminary calculation results showed that the ECC behavior in the upper downcomer of the DVI system and the steam condensation phenomena inside the heat exchanger of the PAFS can be reproduced qualitatively well. The simulation will be continued with more realistic geometries and proper two-phase flow models.

REFERENCES

[1] H. K. Cho, "Scaling Analysis for the Multidimensional Phenomena of the ECC Bypass during an LBLOCA with the Direct Vessel Injection," Ph. D. Thesis, Seoul National University, 2004.

[2] B. U. Bae et al., "Analysis of Condensation Phenomena in PAFS (Passive Auxiliary Feedwater System) Horizontal Heat Exchanger of APR+," KNS Autumn Meeting, October 29-30, Gyeongju, Korea, 2009.

Acknowledgments

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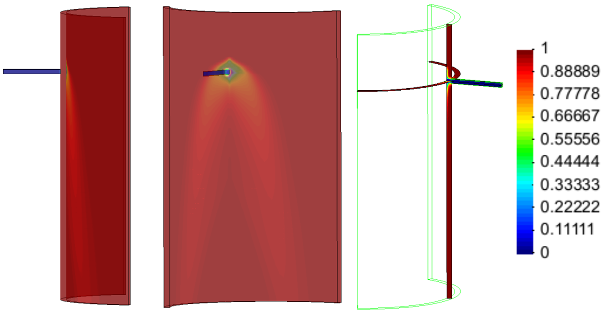

Fig. 1. Liquid film width test simulation result

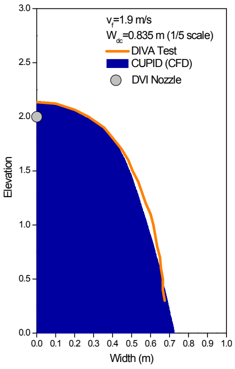

Fig. 2. Comparison result with the experimental data

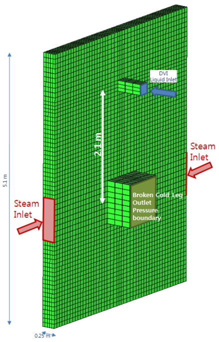

Fig. 3. Boundary conditions of the ECC bypass simulation

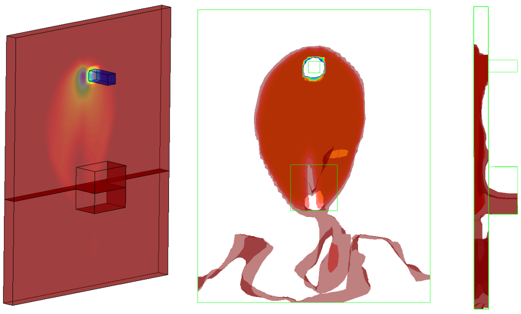

Fig. 4. Direct ECC bypass simulation result: void fraction

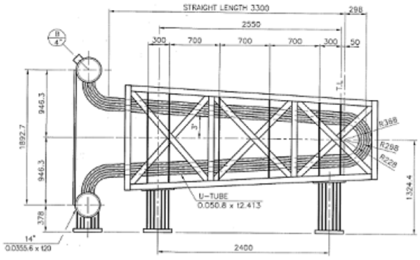

Fig. 5. Design of the heat exchanger in PAFS

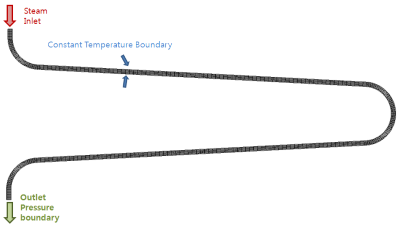

Fig. 6. Boundary conditions of the PAFS tube simulation

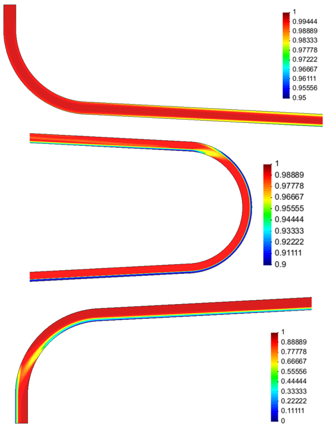

Fig. 7. PAFS tube simulation result: void fraction