Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-18, 2012

Simulation of the Passive Condensation Cooling Tank of the PASCAL Test Facility using the Component Thermal-hydraulic Analysis Code CUPID

Hyoung Kyu Cho [a*], Seung-Jun Lee [a], Han Young Yoon [a]
[a]*Korea Atomic Energy Research Institute, Daedeok-daero 989-111, Daejeon, Korea, 305-353*

[*]*Corresponding author:hkcho@kaeri.re.kr*

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, such as a direct vessel injection system, a gravity-driven safety injection system, and a passive cooling system. 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). Its numerical solver and two-phase flow models have been verified against standard conceptual problems of single and two-phase flows and validated for thermal-hydraulic experiments in our previous studies [2-4].

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 the present study, the PCCT (Passive Condensation Cooling Tank) of the PASCAL test facility was analyzed with CUPID prior to simulating the prototype PAFS system. The objectives of the PASCAL simulation were to validate physical models of CUPID and its applicability to the PAFS analysis. This paper presents the two-dimensional transient calculation results and the comparisons with the experimental data.

2. Computational method

The PASCAL test was conducted to assure the cooling and operational performance of the PAFS. It is composed of a steam supply line, the PCHX (Passive Condensation Heat Exchanger), the PCCT, and a return water line for the condensed water [5]. In the present paper, the PCCT was independently simulated by applying a heat source boundary condition to the PCHX. The PCCT of the PASCAL facility has a slab geometry of which dimensions are 6.7 m wide, 11.5 m high and 0.11 m deep. Assuming that influence of the depth directional flow behavior on overall natural circulation is minor, it was analyzed in two-dimensions and a total of 1815 (33×55) meshes were used as shown in Fig. 1. The PCHX and the supporting structures were modeled using the porous media model and accordingly, the following parameters were incorporated in the solver; porosity, permeability, heat transfer area, wall friction model, form loss coefficient, etc.

In the PCCT, various flow regimes may appear during the transient including a single phase liquid flow, bubbly flow, free surface, and single phase vapor flow as illustrated in Fig. 2. In order to consider these flow patterns in the two-dimensional modeling, the inter-phase surface topology map was applied as a flow regime map for the two-phase flow. Since the heat flux on the PCHX outer surface is lower than the critical heat flux, simplified flow patterns were defined such as the bubble topology, drop topology, sharp interface topology and the interpolation regions among them. Once the local topology is determined for each cell, the interfacial area and interfacial transfer models, thereafter, are defined depending on the topology of each cell.

3. Calculation Results

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. Fig. 3 shows the void fraction distribution change from 0 to 7,000 seconds at every 3,500 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 as presented in Fig. 4. It should be noted that this phase change was induced by a flashing of the water. Due to the hydraulic head of the water, the pressure at the top of the PCHX was 0.173 MPa, and the saturation temperature was 115.7 °C. As a result, the liquid could be heated up over 100°C and then it rose to the free surface along the left side wall. Since the pressure near the free surface was close to the atmospheric one, the liquid became superheated water as it flowed upward and then, a flashing was initiated. After the flashing, the water temperature dropped to the saturation temperature and then, it flowed downward along the other side wall and the two-phase natural circulation was continued. Fig. 4 shows the void fraction distribution at 8,000, 20,000 and 30,000 seconds. Due to the flashing near the free surface, the water level decreased gradually and it reached the PCHX elevation in the end and the heat removal by the two-phase natural circulation was finished. This result showed that the heat removal by the boil-off can be lasted longer than 8 hours (28,800 seconds) as it was designed.

In Fig. 5, the temperature transients at two positions, (0.225 m, 1.41 m) and (0.45 m, 9.5 m) were compared between the calculation and the test. It showed that the trends of the temperature can be quantitatively well reproduced by the CUPID code.

4. Conclusions

In the present study, the CUPID code was applied for the simulation of the PCCT of the PASCAL test facility. It was modeled independently without the PCHX by imposing a heat source boundary condition and the porous media model was applied in order to consider the effect of the distributed structures which give resistance to the natural circulating flow. The inter-phase topology method was employed for the various flow patterns that may appear during the transient of the PCCT. The long transient (30,000 seconds) of the thermal hydraulic phenomena inside the PCCT was successfully simulated and the important characteristics were well reproduced by the CUPID code including the natural circulation and the water level decrease by the boil-off.

Acknowledgments

This work was supported by Nuclear Research & Development Program of the NRF (National Research Foundation of Korea) grant funded by the MEST (Ministry of Education, Science and Technology) of the Korean government.

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," *Nuclear Engineering and Technology*, **42**, pp. 279-296 (2010).

[2] H.Y. Yoon, I.K. Park, Y.J. Lee and J.J. Jeong, "An Unstructured SMAC Algorithm for Thermal Non-equilibrium Two-phase Flows," *International Communications in Heat and Mass Transfer*, **36**, pp. 16-24 (2009).

[3] I.K. Park, H.Y. Yoon, J.J. Jeong, D.J. Euh, H.K. Cho, "An Implementation of the Interfacial Area Transport Equation into the CUPID Code," *Proc. of NUTHOS-8*, Shanghai, China, October 10-14 (2010).

[4] H. K. Cho, B. J. Yun, J. R. Lee and J. J. Jeong, "Computational Analysis of Downcomer Boiling Phenomena Using a Component Thermal Hydraulic Analysis Code, CUPID," *Journal of Engineering for Gas Turbines and Power*, **133**, pp. 052914-1-052914-9 (2011).

[5] B. U. Bae et al., "Experimental Study on Validation of Cooling Capability for PAFS (Passive Auxiliary Feedwater System) Condensation Heat Exchanger with PASCAL Facility," KAERI/TR-4419/2011, Korea Atomic Energy Research Institute (2011).

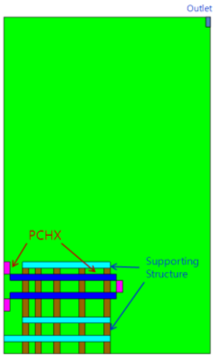


Fig. 1 Computational domain

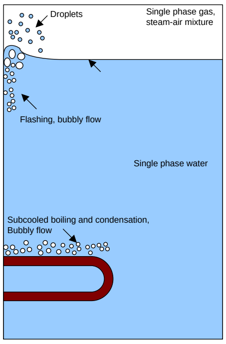
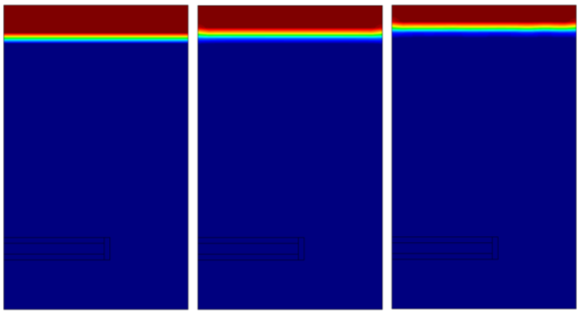
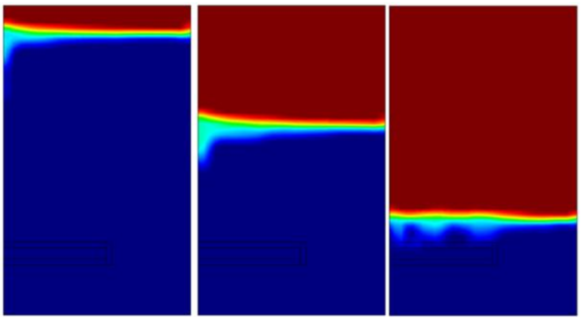


Fig. 2 Thermal-hydraulic phenomena in PCCT



0 sec. 3500 sec. 7000 sec.

Fig. 3 Void Fraction Distribution: swelling



8000 sec. 20000 sec. 30000 sec.

Fig. 4 Void Fraction Distribution: boil-off

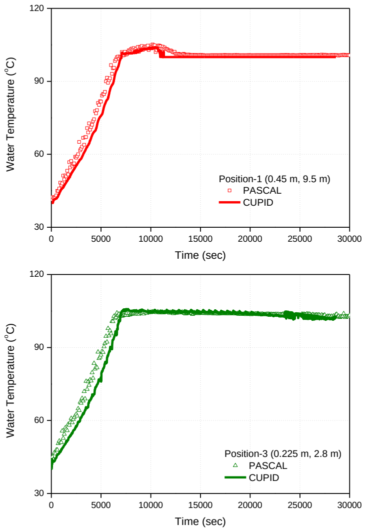


Fig. 5 Temperature transients