# Heat Structure Coupling between CUPID and MARS for the Wall Film Condensation Analysis with Non-condensable Gases

Jehee Lee [a], Goon-Cherl Park [a], Hyoung Kyu Cho [a*]
[a]*Department of Nuclear Engineering, Seoul National Univ., 1 Gwanak-ro, Gwanak-gu, Seoul, 151-744*
[*]*Corresponding author: chohk@snu.ac.kr*

## 1. Introduction

In the reactor containment, wall condensation occurs in the presence of non-condensable gases. In that case, heat transfer rate is reduced significantly because buildup of the non-condensable gases inhibits the diffusion of vapor from the bulk mixture to the liquid film and decreases condensation rate [1]. Therefore, an accurate knowledge of wall film condensation rates is important for the integrity of containment and the performance of safety components that were installed for containment cooling system like Passive Containment Cooling System in accident conditions.

In the present study, CUPID code [2], which has been developed by KAERI, and MARS code are coupled for the simulation of wall film condensation in the presence of non-condensable gases. In order to simulate the condensate heat transfer at the condenser wall, CUPID code is used. On the other hand, MARS code is used for simulate the cooling jacket of the condenser wall.

For the verification of the CUPID-MARS coupled code, COPAIN condensation experiment, which is conducted by CEA, was re-simulated [3] and the results were compared with CUPID code simulation with the constant wall temperature that is calculated before for the validation of CUPID wall film condensation model.

## 2. Coupling CUPID and MARS code

In this section, coupling method for CUPID and MARS code to simulate wall film condensation with the cooling jacket will be introduced. After that, verification of coupled CUPID-MARS code will be followed.

### *2.1 Heat structure coupling of CUPID and MARS code*

To simulate the Passive Containment Cooling System (PCCS), CUPID and MARS code are coupled using heat structure coupling. As shown in Fig. 1, PCCS heat exchangers are installed at the containment wall and wall condensation will be occurred at the heat exchanger tube outside. On the other hand, natural convection and boiling will be occurred at the tube inside. Tube inside behaviors could be simulated with the system codes; however, system codes could not reproduce multi-dimensional phenomena such as wall film condensation and accumulation of Non-condensable gases near the tube outside wall adequately with sufficient resolution of computational meshes [4]. Thus, the multi-dimensional analysis code, CUPID, can be used for the tube outside simulation instead of the 1D code if those two codes are coupled through the heat structure.

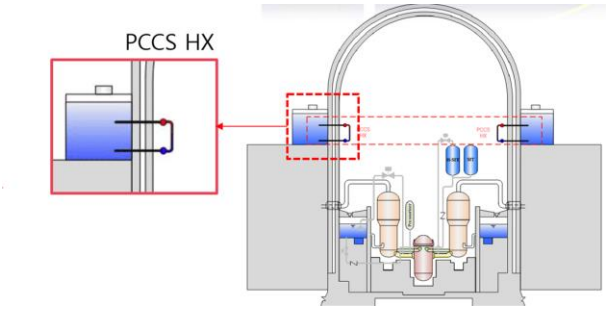


Fig. 1. Schematic diagram of the IPOWER PCCS [5]

For the coupling of CUPID and MARS code, heat structure coupling was used. Source code of MARS-DLL was modified to use the user-defined parameter for the wall heat flux at the heat structure and to visualize the calculation results with SNAP. At the source code of the CUPID, modification for the mapping between the codes was made to couple the CUPID and MARS code as shown in Fig. 2.

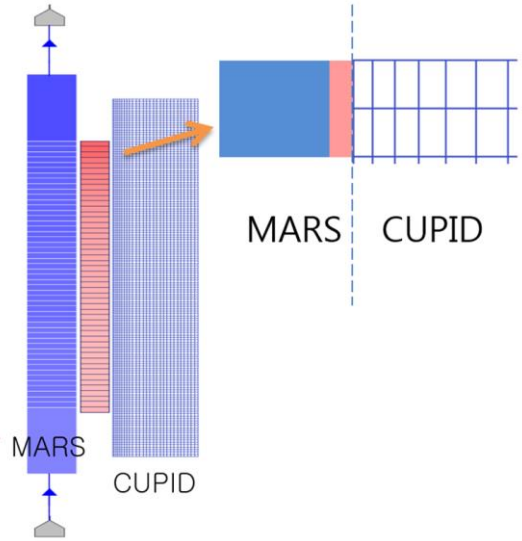


Fig. 2. Schematic diagram of CUPID-MARS coupling calculation

In the coupled code, the wall heat flux that is calculated at the CUPID code is transferred to the MARS code as the wall heat flux boundary condition. On the other hand, the temperature of the heat structure

is transferred for the wall temperature boundary condition of the CUPID code.

### *2.2 COPAIN experiment simulation with coupled CUPID-MARS code*

Using coupled CUPID-MARS code, COPAIN experiment [3] is calculated. Fig. 3 shows the schematic diagram of COPAIN experiment. In the figure, test section is simulated with CUPID wall film condensation model which uses two-fluid model for its governing equation and secondary circuit is analyzed with MARS code. Condenser plate is simulated as heat structure of MARS code, so its temperature data are transferred to CUPID wall temperature boundary condition.

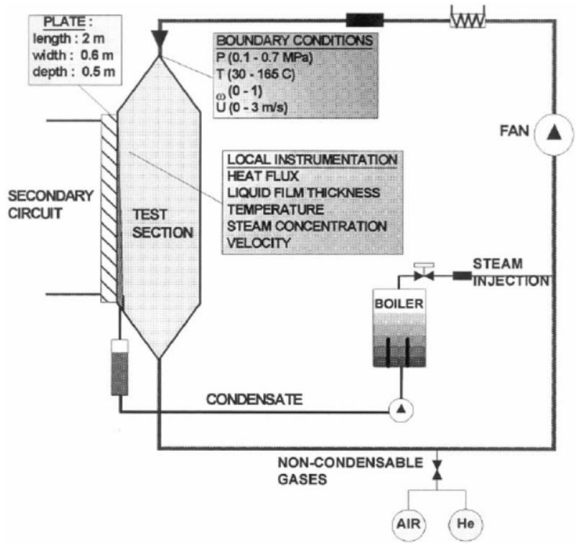


Fig. 3. Schematic diagram of COPAIN experiment

COPAIN P0441, P0443, and P0444 tests are simulated and the results are compared with experiment results and STAR-CCM+ which is commercial CFD code and COPAIN calculation results with constant wall temperature that is calculated for the validation of wall film condensation model of CUPID. [6] The calculation results are shown in Fig. 4. As shown in figure, heat flux results of CUPID-MARS coupling code are almost same with those of constant wall temperature. The error of wall temperature is within 1 K also. From those results, CUPID-MARS coupling is verified.

## 3. Conclusions

In the present study, CUPID code is coupled with MARS code using heat structure coupling. With heat structure coupling, CUPID wall heat flux results could be entered at the MARS code using user-defined parameter for boundary condition. On the other hand, temperature of the heat structure could be transferred for the wall temperature boundary condition of the CUPID code. Using coupled code, COPAIN experiment tests are re-calculated and results are almost same with constant wall temperature calculation results. From those results, CUPID-MARS coupling is verified

In the future, more validation will be performed with coupled code against various experimental databases, not only for the vertical flat plate but also for tube geometry.

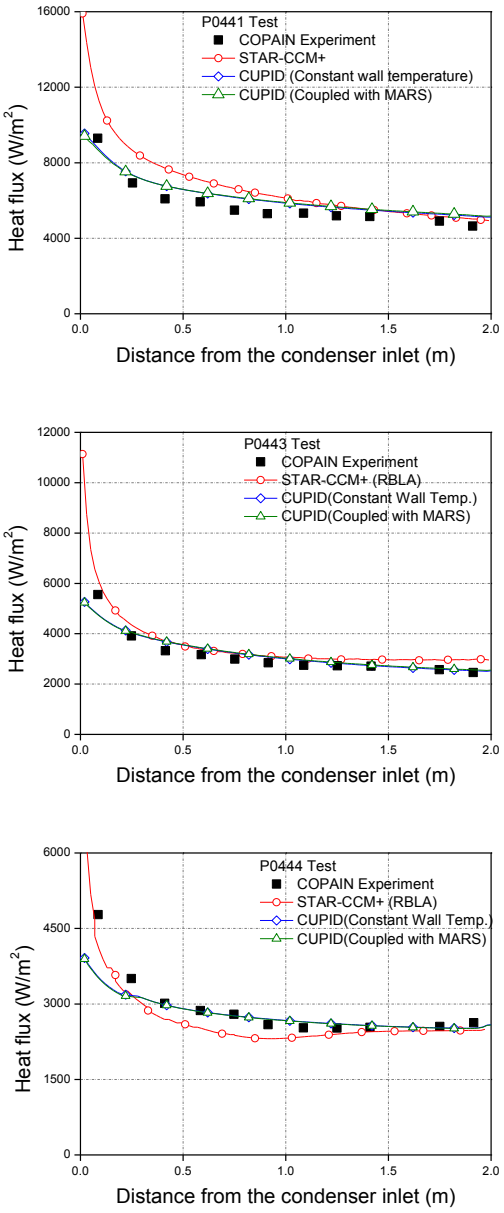


Fig. 4. COPAIN calculation results

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## REFERENCES

[1] A. Dehbi, et al., Prediction of steam condensation in the presence of noncondensable gases using a CFD-based approach, Nuclear Engineering and Design, 258, pp. 199-210, 2013.
[2] H. Y. Yoon, et al., CUPID code manual vol.1: Mathematical Models and Solution Methods, Korea Atomic Energy Research Institute, KAERI/TR-4403/2011.
[3] X. Cheng, et al., Experimental database for containment thermal-hydraulic analysis, Nuclear Engineering and Design, 204, pp. 267-284, 2001.
[4] J. H. Lee, et al., Improvement of CUPID code for Simulating Filmwise Steam Condensation in the Presence of Noncondensable gases, Nuclear Engineering Technology, 47, pp. 567-578, 2015.
[5] H. G. Kim, 신형 원전 안전해석을 위한 실험 프로그램, 2015 원자력 안전해석 심포지엄, 2005.
[6] J. H. Lee, et al., Validation of wall film condensation model in the presence of NC gas for two-fluid model, NUTHOS-11: The 11th International Topical Meeting on Nuclear Thermal Hydraulics, Operation and Safety, Gyongju, Korea, October 9-13, 2016. .