Validation of Wall Film Condensation model in heat structure coupled CUPID-MARS

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

To prevent the further damage in the event of a nuclear power plant accident, the integrity of a nuclear power plant containment building plays an important role. For the containment safety system, a containment cooling system using sprays has been installed in order to maintain the integrity of containment building. Further that, Passive Containment Cooling System (PCCS) which could be operated in the absence of a power supply such as Station Black Out (SBO) situation is being developed. PCCS uses the wall condensation phenomenon at the PCCS heat exchanger tube to condense the released steam from the reactor at the accident. Using steam condensation, PCCS could decrease the pressure inside of the containment building. However, since the inside of the containment building is filled with non-condensable gases such as air and these gases hinder the condensation phenomenon, it is necessary to properly analyze it [1].

In the present study, CUPID [2], which has been developed by KAERI, and MARS are coupled for the multi-scale simulation of wall film condensation in the presence of non-condensable gases. In order to simulate the condensate heat transfer at the heat exchanger outside where the condensation occurs, CUPID with wall film condensation model is used. On the other hand, MARS is used to simulate the cooling jacket of heat exchanger. Coupling method for CUPID-MARS was introduced in Lee et al. [3].

For the validation of the CUPID-MARS heat structure coupled code, CONAN condensation experiment, which is conducted by University of PISA, was simulated [4] and the results were compared with experimental results.

2. Validation of Coupled CUPID-MARS

2.1 CONAN experiment simulation with the coupled CUPID-MARS code

For the validation of coupled CUPID-MARS, CONAN experiment is simulated using the coupled code. The schematic diagram of CONAN is shown in Fig. 1.

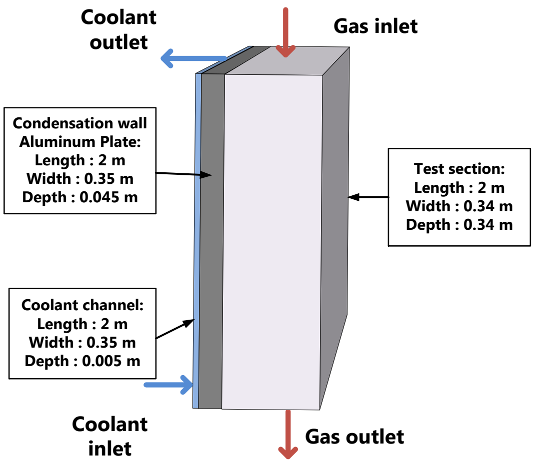

Fig. 1. Schematic diagram of CONAN experiment

As shown in the schematic diagram, the test section of CONAN experiment is a square channel. The condensation plate is 2 m in length, 0.34 m in width. The gas mixture enters from the top of the channel in downward direction at the atmospheric pressure. Wall condensation occurs on the 2 m height, 45 mm thick aluminum plate wall [5]. Condenser plate is cooled by secondary water flowing in a rectangular channel. To simulate the condenser plate and secondary cooling jacket, heat structure coupling is used as shown in Fig.2.

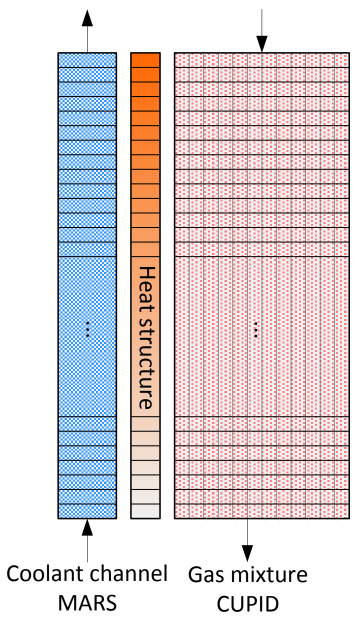

Fig. 2. Schematic diagram of CUPID-MARS coupling calculation

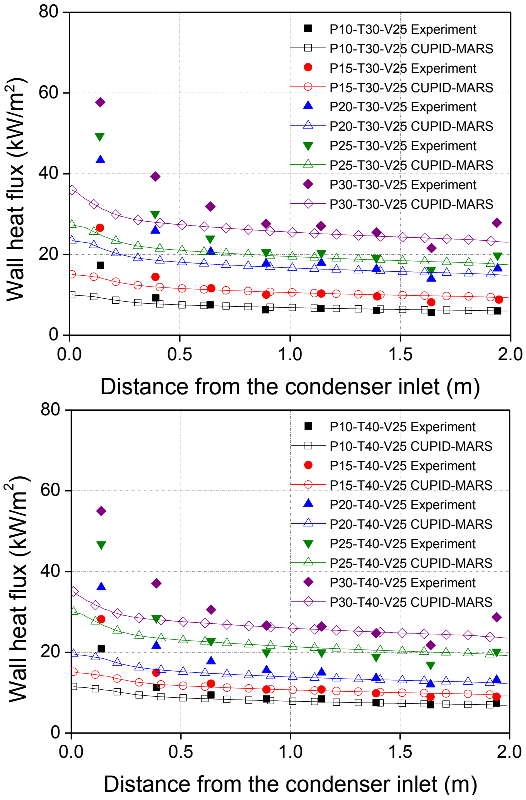

Fig. 3. CUPID-MARS heat flux calculation results

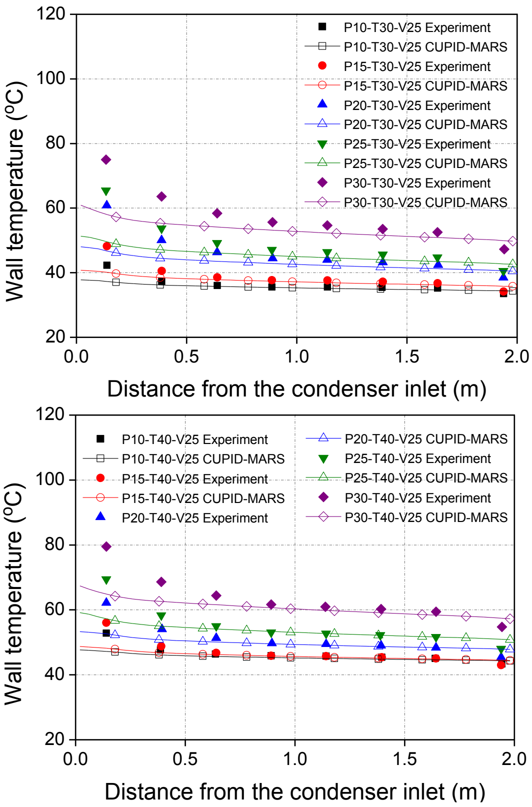

Fig. 4. CUPID-MARS wall temperature calculation results

As shown in Fig.3, 4, the calculation results of CUPID-MARS show a good agreement with the experimental data in the fully developed region. In the developing region, standard wall function has limitation when it is applied to developing flow and thus, the heat flux and wall temperature results were under-predicted.

2.2 Modification of Wall film condensation model using entrance effect factor

In order to modify limitation of the wall function at the developing region, entrance effect factor which is suggested by Siddique et al. [6] is introduced to the coupled CUPID-MARS code.

$$Nu_{o,t} = Nu_o\left[1+\frac{0.8\left(1+7\times10^4\,\mathrm{Re}^{-3/2}\right)}{x/d}\right] \qquad (1)$$

$$Sh_{o,t} = Sh_o\left[1+\frac{0.8\left(1+7\times10^4\,\mathrm{Re}^{-3/2}\right)}{x/d}\right] \qquad (2)$$

With entrance effect factor, CONAN simulation results are modified as shown in Fig. 5, 6. From these results, the limitation of wall function at the entrance region could be covered with adequate entrance effect factor, and that could be increase the accuracy of the code.

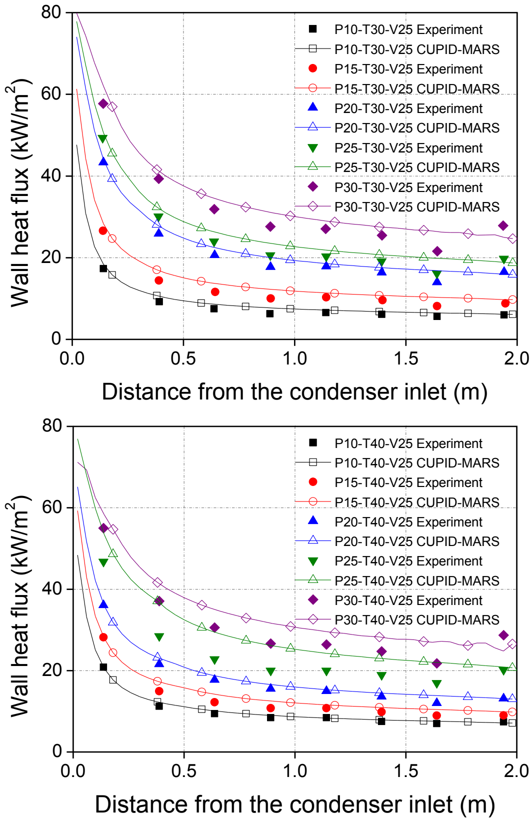

Fig. 5. CUPID-MARS heat flux calculation results with entrance effect factor

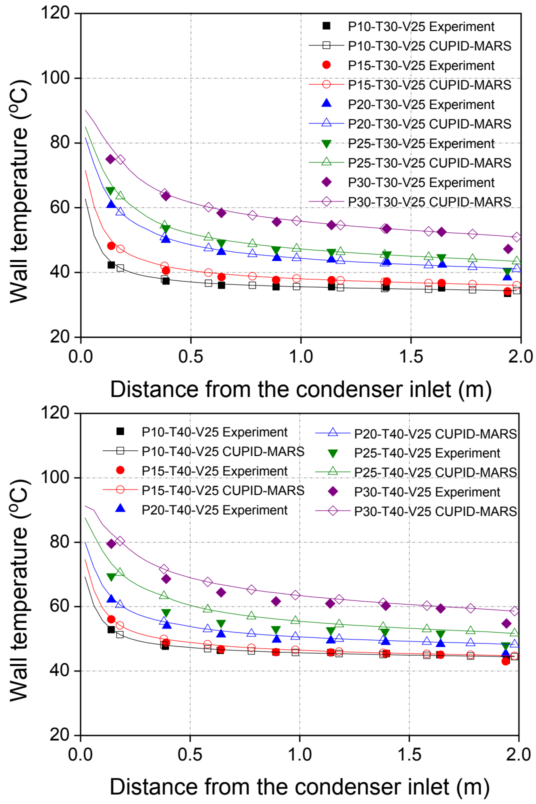

Fig. 6. CUPID-MARS wall temperature calculation results with entrance effect factor

3. Conclusions

In the present study, CONAN experiments were simulated for the validation of the coupled CUPID-MARS code. The heat flux and wall temperature results of the coupled code showed a good agreement with the experiment data in the fully developed region. In the developing region, heat flux was under-predicted since the flow is not fully developed and the wall function has limitation at the developing region. For this reason, entrance effect factor of Siddique was introduced, and the calculation results were modified with the factor.

In the future, more validation will be conducted for different geometry, such as a tube in a heat exchanger and various flow conditions to extend the model's applicability. The entrance effect factor will be extended to natural convection region which may require different correction factor.

Acknowledgement

This work was supported by the Nuclear Safety Research Program through the Korea Foundation Of Nuclear Safety (KoFONS), and was granted financial resource from the Nuclear Safety and Security Commission (NSSC), Republic of Korea (No. 1305011) and the National Research Foundation (NRF) of Korea funded by the MSIP (No. NRF-2015M2B2A9028750).

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