Validation of Wall Film Condensation Model in the presence of the Non-Condensable Gas for CAP

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1. Introduction

The CAP (Containment Analysis Package) code is containment building analysis code for the containment integrity assessment, Emergency Core Cooling System (ECCS) performance assessment, and equipment qualification envelop analysis.[1] In order to improve the performance of the in-pipe flow and two-phase flow analysis of CAP, a pipe component was implemented.[2] A condensation model based on the Colburn-Hougen method is implemented in the pipe component of CAP to analyze wall condensation in the pipe.

In this study, to validate the condensation model of CAP, MIT [3] and KAIST [4] condensation experiments are selected and analyzed, and the calculation results are compared with experiment results.

2. Implementation of Wall Condensation Model

To predict the wall film condensation heat transfer in the presence of non-condensable gases, a condensation model based on the Colburn-Hougen method was implemented.

The gas/liquid side heat flux is calculated as below.

$$q_t'' = h_m h_{fgb} \rho_g \ln\left(\frac{1 - \frac{P_{vi}}{P}}{1 - \frac{P_{vb}}{P}} \right) = h_c \left(T_{vi} - T_w \right)$$

h_m : Mass transfer coefficient [*m/s*]

$T_{vi} = T_{sat}\left(P_{vi}\right)$ (Interface temperature [K])

$\rho_g = \rho_{sat}\left(P\right)$ [*kg/m³*]

P : Total pressure [*Pa*]

P_{vi} : Steam partial pressure at the interface [*Pa*]

P_{vb} : Steam partial pressure at the bulk [*Pa*]

$h_{fgb} = h_{fg,sat}\left(P_{vb}\right)$ (Latent heat at the bulk [*J/kg*])

In here, for the mass transfer coefficient, Gilliand (forced convection), Rohsenow-Choi (Laminar flow), and Churchill-Chu (Natural convection) models are used. To calculate the heat flux, interface temperature and vapor partial pressure should be obtained by iterative method. With above equation and convective heat transfer, wall heat transfer rate when wall condensation occurs could be calculated.

3. Validation of Wall Condensation Model

The MIT experiment and KAIST experiment were analyzed to validate the wall film condensation model in CAP.

3.1 MIT vertical condensation tube experiment

The schematic diagram of the MIT experiment was shown in Fig. 1. The CAP code modeling for MIT experiment consists of one PIPE component, nine heat structures, and inlet and outlet boundary conditions, as shown in Figure 2. The PIPE component is modeled to be a vertical downward pipe and consists of 11 cells. The vertical condensation tube is modeled with 9 cells (p1~p9), 2.54 m in length and 0.0016619 m^2 in the flow area.

The calculation results are shown in Fig. 3 to Fig. 5. As shown in figures, CAP condensation model reasonably predicts the heat transfer coefficient with in an uncertainty of 20%.

3.2 KAIST vertical condensation tube experiment

The schematic diagram of the KAIST experiment was shown in Fig. 6. The CAP code modeling for KAIST experiment consists of one PIPE component, nine heat structures, and inlet and outlet boundary conditions, as shown in Figure 7. The PIPE component is modeled to be a vertical downward pipe and consists of 13 cells. The vertical condensation tube is modeled with 11 cells (p1~p11), 2.4 m in length and 0.001772 m^2 in the flow area.

The calculation result is shown in Fig. 8. As shown in figure, CAP condensation model reasonably predicts the heat transfer coefficient with in an uncertainty of 20%.

4. Conclusion

In this study, the film condensation model based on Colburn-Hougen method is implemented CAP to improve the wall heat transfer analysis performance. For the validation of condensation model, MIT and KAIST experiments were analyzed, and the calculation results show that wall film condensation model is implemented into CAP appropriately.

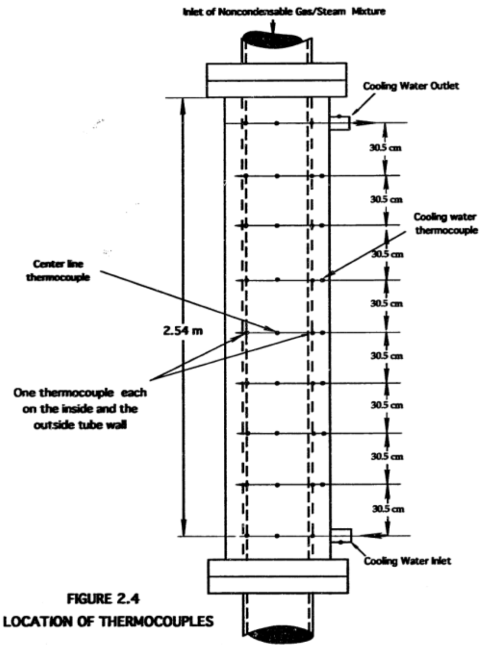

Fig. 1. Schematic diagram of MIT condensation experiment

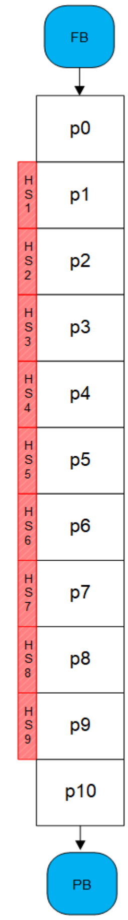

Fig. 2. Nodalization of MIT experiment

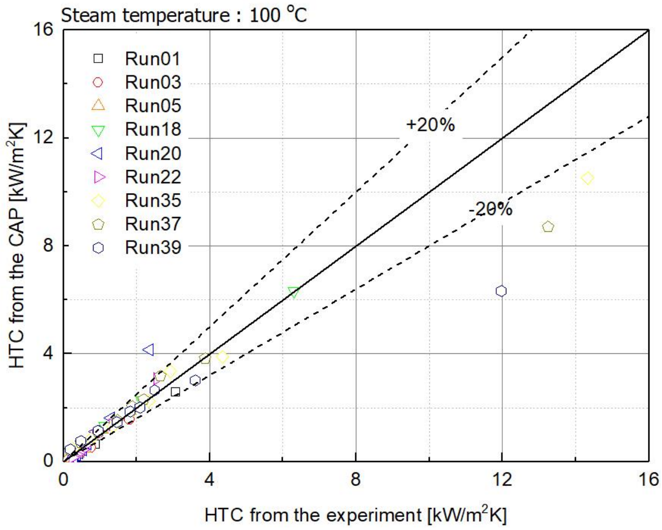

Fig. 3. MIT experiment calculation results (100°C Saturation Temperature)

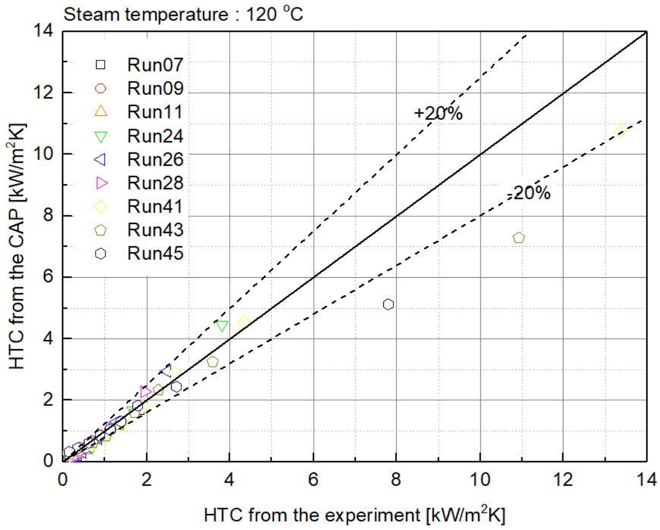

Fig. 4. MIT experiment calculation results (120°C Saturation Temperature)

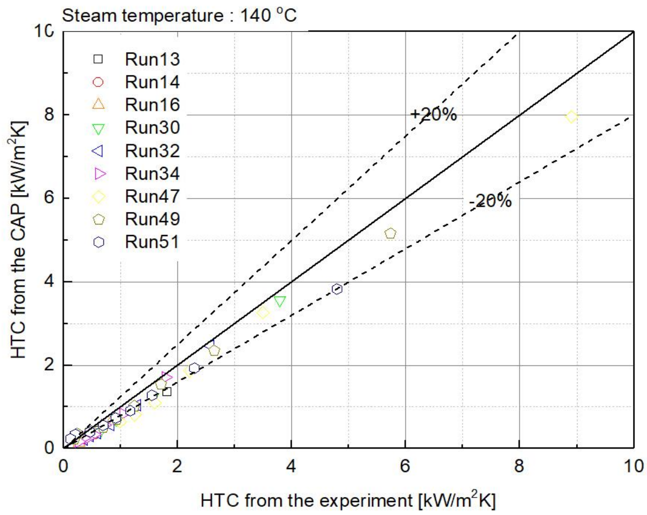

Fig. 5. MIT experiment calculation results (140°C Saturation Temperature)

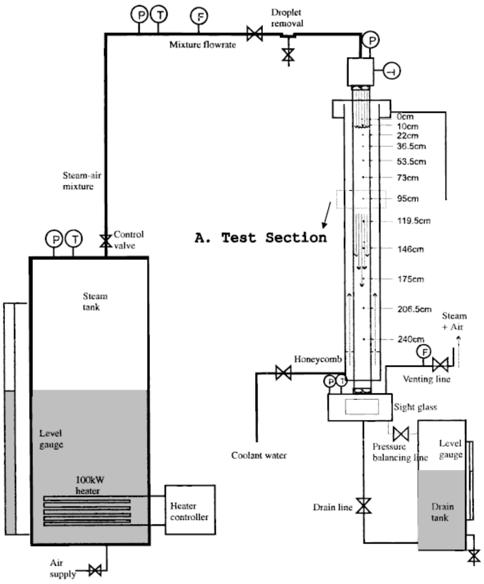

Fig. 6. Schematic diagram of KAIST condensation experiment

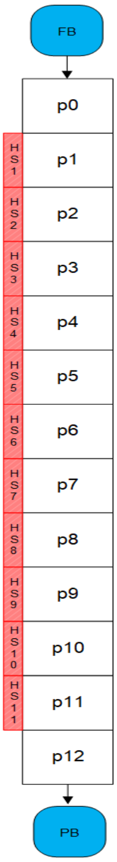

Fig. 7. Nodalization of KAIST experiment

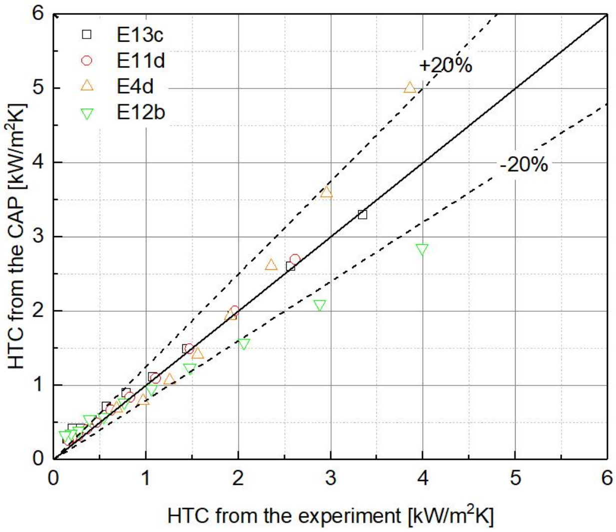

Fig. 8. KAIST experiment calculation results

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