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Prediction of Heat Removal Capacity of Horizontal Condensation Heat Exchanger submerged in Pool

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1. Introduction

In nuclear engineering field, for the improvement of groundbreaking safety and public acceptance, the horizontal U-shaped condensation heat exchanger submerged in a pool is under development as a core equipment of a passive safety system. As representative passive safety systems, there are the passive containment cooling system (PCCS) of ESBWR, the emergency condenser system (ECS) of the SWR-1000, the passive auxiliary feed-water system (PAFS) of the APR+ and etc. During the nuclear power plant accidents, these passive safety systems can cool the nuclear system effectively via the heat transfer through the steam condensation, and then mitigate the accidents.

For the optimum design and the safety analysis of the passive safety system, it is essential to predict the heat removal capacity of the heat exchanger well. The heat removal capacity of the horizontal condensation heat exchanger submerged in a pool is determined by a combination of a horizontal in-tube condensation heat transfer and a boiling heat transfer on the horizontal tube. Since most correlations proposed in the previous nuclear engineering field were developed for the vertical tube, there is a certain limit to apply these correlations to the horizontal tube. Therefore, this study developed the heat transfer model for the horizontal U-shaped condensation heat exchanger submerged in a pool to predict well the horizontal in-tube condensation heat transfer, the boiling heat transfer on the horizontal tube and the overall heat removal capacity of the heat exchanger using the best-estimate system analysis code, MARS.

2. Prediction of horizontal in-tube condensation

The horizontal in-tube condensation can be predicted by a condensation model for each flow regime. In order to predict the horizontal in-tube condensation heat transfer of the steam-water two phase flows, it is essential to assess the prediction capability of the previous models because the previous models were developed using refrigerants and organic fluids as working fluids. This study assessed the prediction capability of the previous horizontal in-tube condensation models for the annular and stratified flow which are main flow regimes encountered in a horizontal condenser. Furthermore, this study selected good models for the prediction of the horizontal in-tube condensation heat transfer for each flow regime.

Using MARS code, total 11 stratified flow condensation models were assessed with experimental data obtained from Purdue-PCCS, JAEA-PCCS, PASCAL and NOKO experiment. From the assessments, it was confirmed that the Cavallini et al. (2006) model showed good agreement with the experimental data for various test conditions (see Fig. 1).

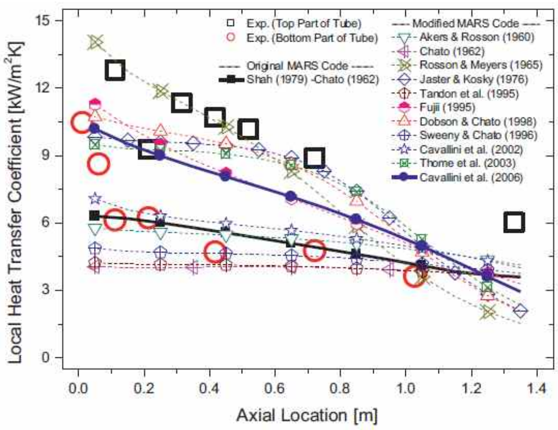

Fig. 1. Local heat transfer coefficients (Purdue-PCCS, Case 101)

Using MARS, total 19 annular flow condensation models were assessed with experimental data obtained from JAEA-PCCS, PASCAL and NOKO experiment. From the assessments, it was confirmed that the Dobson-Chato (1998) model showed good agreement with the experimental data (see Fig. 2).

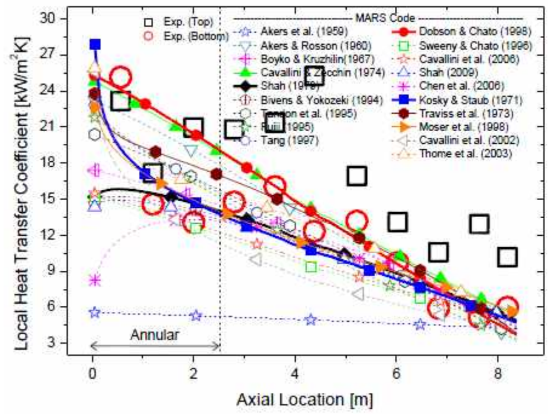

Fig. 2. Local heat transfer coefficients (PASCAL, SS-540-P1)

This study selected the Dobson and Chato (1998) model as an annular flow condensation model and Cavallini et al. (2006) model as a stratified flow model for the steam-water two phase flows.

3. Prediction of boiling heat transfer on horizontal tube

In order to predict the boiling heat transfer on the horizontal tube for water, it is essential to assess the prediction capability of the previous models. Using MARS code, 7 pool boiling model and 2 forced convection boiling models were assessed with experimental data obtained from PASCAL. From the assessments, it was confirmed that there are no models to predict the local heat transfer coefficients of PASCAL experiment. Therefore, it is essential to develop the boiling model for the horizontal U-shaped condensation heat exchanger submerged in a pool.

This study developed the boiling model for the horizontal U-shaped condensation heat exchanger submerged in a pool considering the key mechanism of the experiments. Figures 3 and 4 show the MARS prediction of the local heat transfer coefficients for PASCAL experiments. New model predicted the local heat transfer coefficients of the top and bottom tube of the U-shaped tube well.

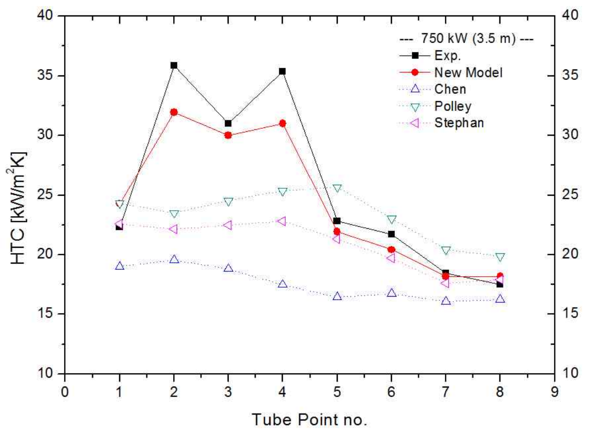

Fig. 3. Local heat transfer coefficients (PASCAL)

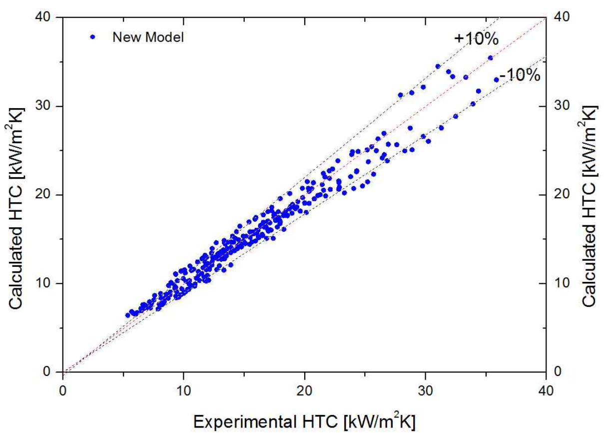

Fig. 4. Local heat transfer coefficients (PASCAL)

4. Prediction of heat removal capacity of horizontal condensation heat exchanger submerged in pool

This study developed the heat transfer model for the horizontal U-shaped condensation heat exchanger submerged in a pool by combining the proposed condensation model and the developed the boiling model. The heat exchanger model predicted the overall heat removal rate well for the PASCAL and NOKO experiments (see Figs. 5 and 6).

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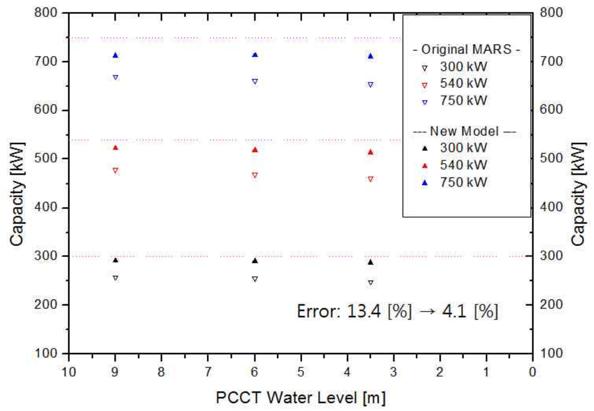

Fig. 5. Overall heat removal rate (PASCAL)

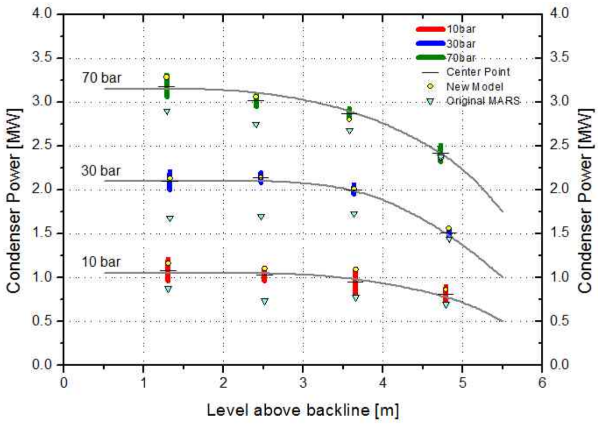

Fig. 6. Overall heat removal rate (NOKO)

3. Conclusions

In this study, the heat transfer model for the horizontal U-shaped condensation heat exchanger submerged in a pool was developed to predict the horizontal in-tube condensation heat transfer, the boiling heat transfer on the horizontal tube and the overall heat removal capacity of the heat exchanger well. It is expected that this model is helpful to the optimum design and the safety analysis of the passive safety system.

ACKNOWLEDGMENTS

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