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Improvement of the Post-CHF Heat Transfer Model in the MARS Code

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1. Introduction

The post-CHF (post-critical heat flux) heat transfer under low flow conditions plays an important role in the thermal hydraulic behavior of research reactors and advanced nuclear reactors as well as in the accident analyses of light water reactors. In the present paper, a 3x3 rod bundle post-CHF was calculated using the form of a one-dimensional three-field model of the MARS code [1]. In order to improve the prediction capability of the post-CHF heat transfer, the Bromley correlation of the MARS code was replaced with the look-up table and a correction factor for the film boiling heat transfer [2, 3]. The modified MARS code shows a good prediction capability in low pressure and low flow conditions.

2. Modification of the Post-CHF Model in the MARS Code

As shown in Figure 1, the test section has a flow housing (39.8 x 39.8 mm^2) inside a pressure vessel where nine heater rods having a heated length of 3,673 mm are located. The heater rods have a symmetric cosine axial heat flux and have a diameter of 9.52 mm and pitch of 12.6 mm. A detailed description of the experiment can be found in Moon et al. [4].

The 3x3 rod bundle was modeled using the one-dimensional calculation of the MARS code version 3.0a. Figure 1 shows the one-dimensional nodalization scheme for the 3x3 rod bundle test section. The inlet and outlet plenums of the test section were treated as boundary conditions. In order to reflect the axial heat flux profile, the heated length of the heater rods was non-uniformly divided into 46 nodes. The upper half region of the heater rods in which a post-CHF heat transfer is expected to occur has more fine nodes than the lower half region. The boundary condition of the heater rods was treated as a convective heat transfer from a rod bundle without a cross-flow. Thus, the rod pitch-to-diameter was inputted in the boundary condition to model the effect of the rod bundle on the calculation of the critical heat flux.

The internal geometry of the heater rods is modeled in detail. The test section shroud is also modeled because the cold wall can affect the CHF and the post-CHF heat transfer.

Groeneveld et al. [2] developed the look-up table for the fully-developed film boiling heat transfer for a round tube with a diameter of 8 mm. The heat transfer coefficients are tabulated as a function of the pressure, mass flux, quality and wall superheat. Guo and Groeneveld [3] suggested a correction factor in order to apply the look-up table to the developing film boiling heat transfer regime. This look-up table and correction factor were implemented into the MARS code as follows:

Heat transfer coefficient for the fully-developed film boiling for a hydraulic diameter D:

$$h_{FDFB} = h_{FDFB,D=8mm}(P,G,X,T_W - T_{sat}) \times (0.008/D)^{0.2},$$

correction factor for a developing film boiling regime:

$$k = (h_{FB} - h_{FDFB})/(h_{NB} - h_{FDFB}) = \exp[-a(WSR-1)^b],$$

$$WSR = (T_W - T_{sat})/(T_{CHF} - T_{sat})$$

heat transfer coefficient for a film boiling:

$$h_{FB} = kh_{NB} + (1-k)h_{FDFB},$$

$$T_{CHF} = T_{sat} + q''_{CHF}/h_{NB}.$$

Where a and b are constants, and h_{NB} is the nucleate boiling heat transfer coefficient. T_W, T_{CHF}, T_{sat} are the wall temperature at a film boiling, the wall temperature at a CHF, and the saturation temperature, respectively.

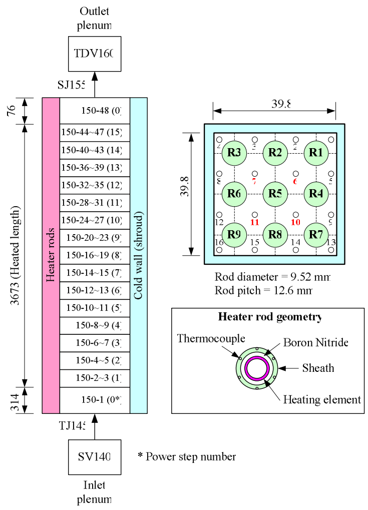
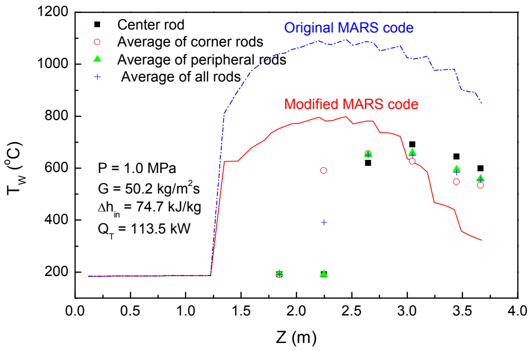


Figure 1. MARS 1-D nodalization

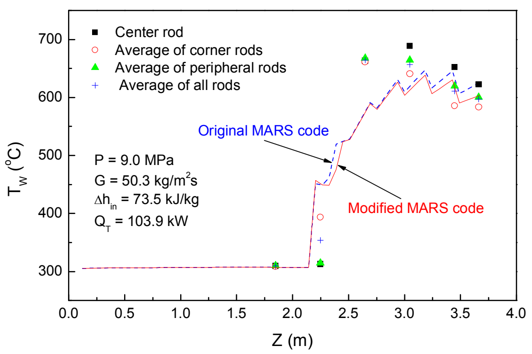
3. Results and Discussion

Figure 2 shows the predicted wall temperature profiles along the heated length at two different pressures. The CHF location is not changed because the original and modified MARS codes use the same CHF look-up table. However, the modified MARS code shows better prediction results for the post-CHF at low pressures when compared with the original code using Bromley's correlation. The original MARS code generally overestimates the wall temperature at the post-CHF condition, especially for low pressure and low flow conditions as shown in Figures 3 and 4. The prediction capability of the MARS code is improved significantly under the low pressure and low flow conditions. Figure 5 shows the predicted wall temperature against the measured average wall temperature. Here, the measured average wall temperature means the arithmetic mean of the wall temperatures of all 3x3 heaters at the same given axial location. The overestimation by the original MARS code is reduced significantly by the modified post-CHF correlation.

The look-up table for the fully-developed film boiling heat transfer and the correction factor for the developing film boiling heat transfer are based on a large amount of post-CHF heat transfer data for a round tube. However, the assessment of this study shows that the look-up table and the correction factor can be used even for a rod bundle.



(a) P = 1.0 MPa



(b) P = 9.0 MPa

Figure 2. Prediction of heater wall temperature

3. Conclusion

The Bromley correlation of the MARS code was replaced with a look-up table and a correction factor for the post-CHF heat transfer. The modified MARS code shows a significant improvement for the prediction capability of a post-CHF heat transfer, especially for the low flow and low pressure conditions.

Acknowledgements

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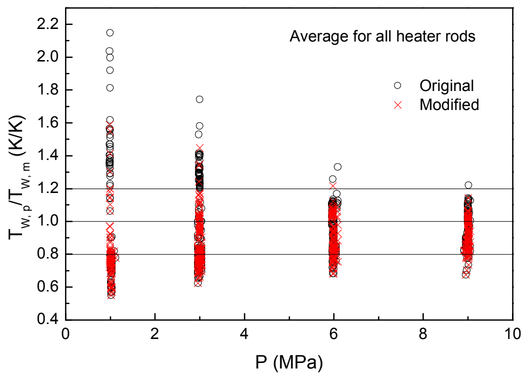

Figure 3. Prediction errors against pressure

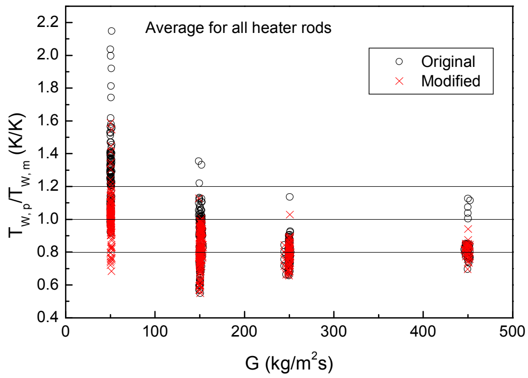

Figure 4. Prediction errors against mass flux

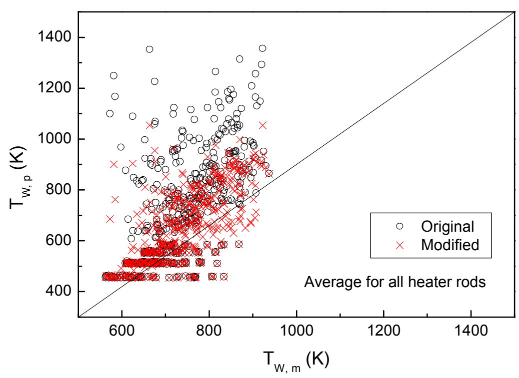

Figure 5. Predicted average wall temperature

REFERENCES

[1] B. D. Chung, S. W. Bae et al., Development and Assessment of Multi-Dimensional Flow Models in the Thermal-Hydraulic System Analysis Code MARS, KAERI/TR-3011/2005, 2005.
[2] D. C. Groeneveld, L. K. H. Leung et al., A Look-Up Table for Fully Developed Film-Boiling Heat Transfer, Nucl. Eng. Design, Vol.225, p.83, 2003.
[3] Y. Guo, L. K. H. Leung, Developing Film Boiling Heat Transfer in Tubes, NURETH-11, Avignon, France, 2005.
[4] S. K. Moon, S. Y. Chun et al., An Experimental Study on Post-CHF Heat Transfer for Low Flow of Water in 3x3 Rod Bundle, Nucl. Eng. Tech., Vol.37, No.5, p.457, 2005.