Prediction of the Critical Heat Flux for a 3x3 Rod Bundle Using MARS Code

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1. Introduction

The critical heat flux (CHF) is a thermal hydraulic phenomenon of great importance for the development and safety analysis of nuclear reactors. The CHF has traditionally been evaluated using empirical correlations or look-up tables. In the present paper, a 3x3 rod bundle CHF was calculated using the form of one-dimensional three-field model of MARS code [1]. This allows a more fundamental mechanistic prediction of the CHF. The heater rods and cold wall was modeled in detail to calculate the wall temperature trace of the heater rods. The CHF was determined by the heater wall temperature excursion. Compared with a direct application of the CHF correlations, the present CHF prediction by the MARS code shows a good CHF prediction capability.

2. Prediction Methods Using 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 3673 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. The sheath and heating element of the heater rods are made of Inconel 600 and Nichrome, respectively. The Inconel sheath and heating element are electrically isolated by boron nitride. A detailed description of the experiment can be found in Ref. [2].

KAERI has developed the three-dimensional best-estimate system code, MARS, which uses a two-fluid, three-field model for two-phase flow [1]. In this study, by assuming one-dimensional flow, the 3x3 rod bundle was modeled using the one-dimensional calculation of the MARS code. 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 CHF is expected to occur has more fine nodes than the lower half region. The boundary condition type of the heater rods was treated as convective heat transfer from a rod bundle without 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.

The heater rod power increased gradually in small steps, 1% increase of the expected critical power during every 30 seconds, until the CHF occurs. The CHF conditions are determined to be reached when one of the wall temperatures predicted by MARS code shows a continuous sharp increase and then become 100 K higher than the saturation temperature.

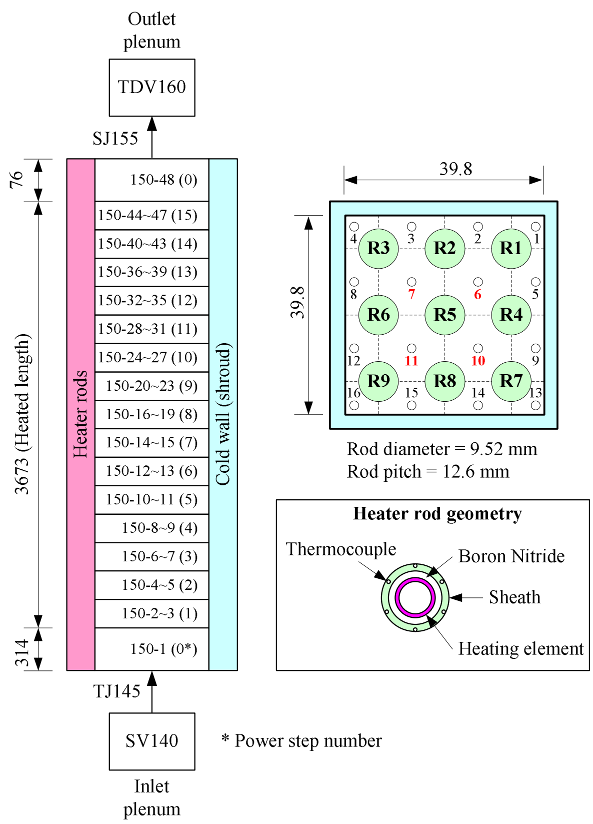

Figure 1. MARS 1-D nodalization

3. Prediction Results and Discussion

In the MARS code, the heat transfer regime is assumed to be post-CHF if the wall superheat is greater than 100 K or the local heat flux is greater than the CHF. The CHF calculation is based on the 1986 AECL-UO look-up table.

A total of 299 CHF data are predicted by the MARS code. Figure 2 shows the abrupt wall temperature excursion at the CHF. Figures 2 thorough 5 show the CHF prediction results by the MARS code. The MARS code predicted the total power at CHF with average error of 4.4% and RMS error of 12.0%. When directly applied to the CHF data, the 1995 CHF look-up table showed the best CHF prediction among several CHF correlations, and had average and RMS errors of -3.5% and 12.8%, respectively [2]. Compared with this prediction result, the present CHF prediction using one-dimensional approach of the MARS code shows a good CHF prediction capability. In the present modeling, the heater wall temperature is governed by heat conduction through the heater rods, two-phase flow heat transfer and CHF. The CHF calculated by the 1986 AECL-UO look-up table is used just only for the determination of the heat transfer regime boundary.

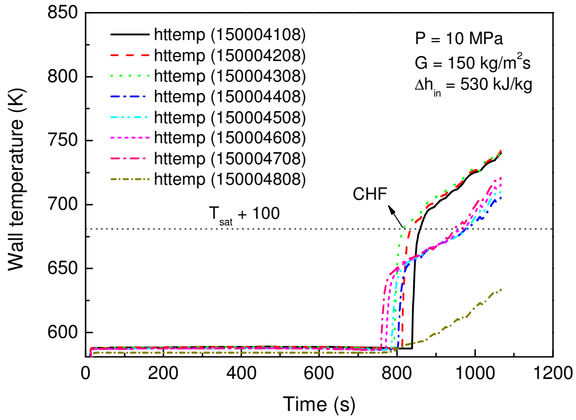

Figure 2. Typical wall temperature trends at CHF

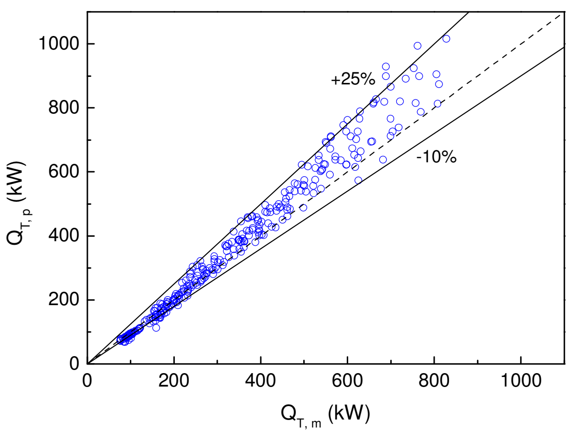

Figure 3. Prediction results for total critical power

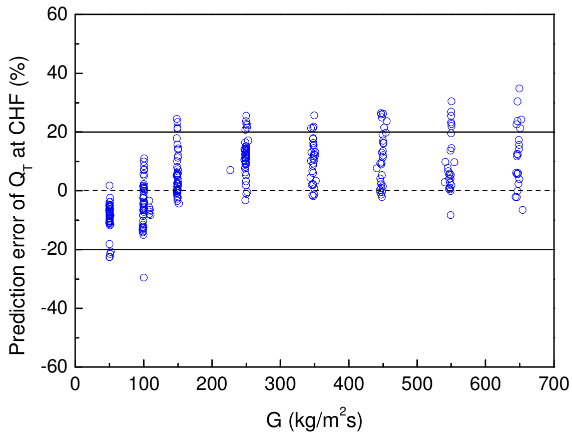

Figure 4. Effect of mass flux on the prediction results

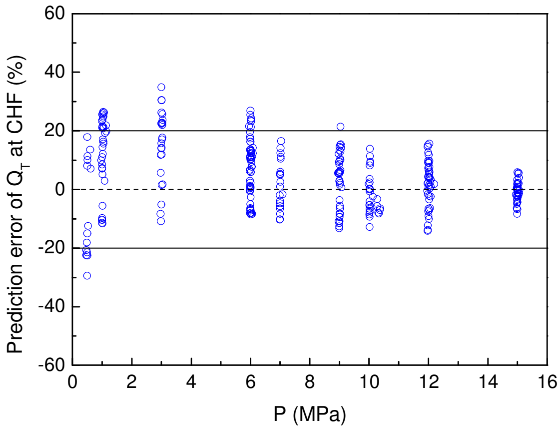

Figure 5. Effect of pressure on the prediction results

As shown in Figures, the MARS code slightly over-predicts the CHF at low pressure conditions less than 6 MPa. The CHF prediction becomes worse as the pressure is decreased. The main reason for this worse prediction at low pressure conditions is due to the use of the 1986 AECL look-up table, which dose not show a reliable CHF prediction at low flow and low pressure conditions [3].

4. Conclusion

The critical heat flux for 3x3 rod bundle was calculated using one-dimensional approach of the MARS code. The MARS code predicted the total power at CHF with average error of 4.4% and RMS error of 12.0%. Compared with a direct application of the CHF correlations, the MARS code shows a good CHF prediction capability. As a future study, the 3x3 rod bundle will be predicted using three-dimensional approach of the MARS code.

Acknowledgements

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References

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[3] W. P. Baek, H. C. Kim et al., An Independent Assessment of Groeneveld et al.'s 1995 CHF Look-Up Table, Nucl. Eng. Design, 178, 331-337, 1997.