MARS Code Reflood Model Improvements and Comparisons with Flecht-Seaset and RBHT Tests

Moonkyu Hwang*, Bub-Dong Chung
Korea Atomic Energy Research Institute
Corresponding author: mkhwang@kaeri.re.kr

1. Introduction

The ability of the MARS code for predicting the consequence of the LBLOCA, especially the peak cladding temperature (PCT) during the accident, is essential in ECCS performance analysis. Due to the wide range of boiling processes including the highly violent heat transfer between the fuel cladding and the injected coolant, however, the existing model in the MARS code under-estimate the peak cladding temperature during the reflood in Flecht-Seaset tests. Since the reflooding models of MARS code is essentially same as those incorporated in the RELAP code, the same peak temperature under-prediction is observed in RELAP5/MOD3 code [1]. For a better prediction of the MARS code during the reflood phase, this study was aimed at improving the existing reflood model of the MARS code.

2. Model Improvements

2.1Wall Heat Transfer for Dispersed Flow Film Boiling

The wall heat transfer in the DFFB regime comprises a wall to vapor heat transfer as well as a wall to liquid heat transfer. The model originally incorporated in MARS code for the wall to vapor heat transfer is the Dittus-Boelter model for a pipe, weighted by the void fraction α_g. For the model improvement, the model proposed by Bajorek and Young [2,3] is incorporated:

$$h_{cwv} = F_{grid} F_{2\Phi} \left[F_{lt} h_{lam} + (1 - F_{lt}) h_{turb} \right], \text{(Eq.1)}$$

where F_{lt} is a linear function that has a value of 1.0 at Rev=3000 and a value of 0.0 at Re_v=10000. For the laminar and turbulent heat transfer coefficients, Nu number of 10 and Dittus-Boelter are used respectively.

The space grid effect represented by F_{grid} in Eq. 1 is modeled by Yao's model incorporated in WCOBRA-TRACE [4]. The droplet enhancement factor $F_{2\Phi}$ in Eq. 1 accounts for the wall to vapor heat transfer increase due to the presence of liquid droplet within the vapor stream, and is modeled in a similar way as in TRACE code (USNRC, 2007):

$$F_{2\Phi} = \left[1 + 25 \frac{(1-\alpha_g) \cdot Gr_{2\Phi}}{\mathrm{Re}_g^2} \right]^{1/2}, \qquad \text{(Eq.2)}$$

where $Gr_{2\Phi}$ is a two-phase grashof number.

The wall to liquid heat transfer in the Dispersed Flow Film Boiling (DFFB) is also modeled as suggested by Bajorek and Young (2000):

$$h_{dcht} = (K_1 K_2) \left(\frac{\pi}{4} \right) \left(\frac{6}{\pi} \right)^{3/4} (1-\alpha_g)^{2/3} \times \left[\frac{k_g^3 i_{fg} g \rho_f \rho_g}{(T_w - T_{sat}) \mu_g D_d} \right] \qquad \text{(Eq. 3)}$$

where $(K_1 K_2)$ accounts for several unknowns involved in detaining the effectiveness of a droplet in making contact with the wall, and the following correlation developed by Bajorek and Young [2] is used.

$$K_1 K_2 = \left[\frac{\mathrm{Re}_g - 4000}{100000} \right]^{0.6}, \qquad \text{(Eq. 4)}$$

where $(K_1 K_2)$ is 0.0 if Re_g < 4000, i.e. the direct contact heat transfer between the droplet and the wall is diminished as the level of the turbulence is not enough to supply the drops with momentum toward the wall.

2.2 Wall Heat Transfer for Inv. Annular Film Boiling

When the void fraction α_g is less than 0.6, an inverted annular film boiling (IAFB) is assumed. In this flow regime, the film boiling model suggested by the PSI which was originally incorporated in the MARS code and RELAP code is maintained without change (ISL, 2006).

2.3 Wall Heat Transfer for Inv. Slug Film Boiling

Between the DFFB region and IAFB region exists the inverted slug film boiling (ISFB) region. For this region the interpolation scheme used in TRACE code is incorporated when 0.6 < α_g < 0.9. The interpolation scheme ensures a smooth transition between the DFFB and ISFB as well as between the ISFB and IAFB.

2.4 Top Quench Front Model

In the original PSI model incorporated in MARS code, the magnitude of the wall heat transfer coefficient is altered if the point in question is close to the top quenching position. A criterion for the top quenching is added to prevent top quenching when the gas velocity is higher than the critical value:

$$v_g > \frac{3.2\left[\sigma g\left(\rho_f - \rho_g\right)\right]^{1/4}}{\left(\rho_g\right)^{1/2}} \qquad \text{(Eq. 5)}$$

3. Results

The code calculations were performed by using the original MARS code and the modified version of the code for the selected Flecht-Seaset tests and the RBHT tests.

The comparison calculations for test 31504 show that the PCTs by the modified MARS version are much closer to the measured data set, whereas there is no apparent change with respect to the quenching time in this particular case (Fig.1). At the higher location of 3.04m, both the PCT and quenching time are seen to have improved with the modified version (Fig.2). Similar improvements with less degree are observed in the case of test 31302 and test 31701.

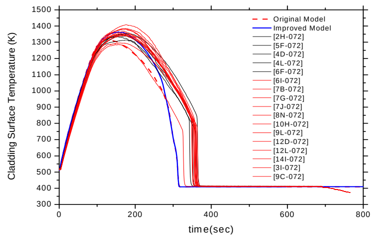

Fig.1 Test 31504 cladding temperatures at 1.93m high

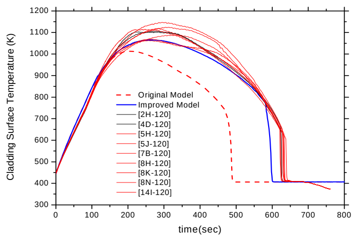

Fig. 2 Test 31504 cladding temp. at 3.04m high

In the case of the RBHT assessment, the improvements over the original MARS are found to be marginal. Fig. 3 and 4 show the cladding temperatures of test 1383 at 2.55m and 3.34m high, respectively. As seen from the figures, the PCTs are overpredicted even though quenching times are improved. Similarly, PCT overpredictions are observed in test 1196 and 1407, especially at the higher locations. The space grid effect, however, is clearly seen from the modified version of the MARS code (see Fig. 5).

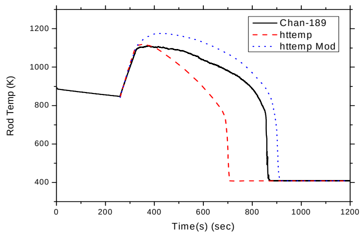

Fig. 3 RBHT Test 1383 cladding temp. at 2.55m high

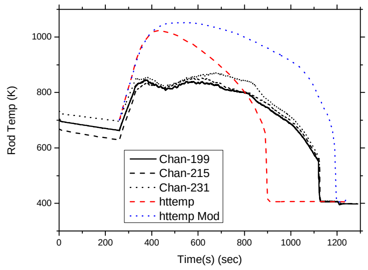

Fig. 4 RBHT Test 1383 cladding temp. at 3.34m high

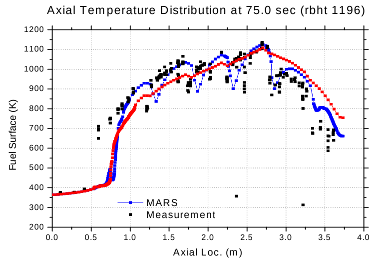

Fig. 5 Axial cladding temp. at 75 sec. (test 1196).

4. Conclusions

The reflood model of the MARS code has been modified to improve the PCT and quenching time. Assessment calculations are performed for the original and modified MARS codes for the Flecht-Seaset test and RBHT test. Improvements are observed in terms of the PCT and quenching time in the Flecht-Seaset assessment. In the case of the RBHT assessment, the improvement over the original MARS is found to be marginal. The space grid effect, however, is clearly seen in the modified version of the MARS code.

REFERENCES

[1] Information System Laboratories, Inc., 2006, RELAP5/ MODE3.3 Code Manual Volume IV: Models and Correlations

[2] S. M. Bajorek, and M. Y. Young, 2000,"Direct-contact Heat Transfer Model for Dispersed-Flow Film Boiling," *Nuclear Technology* V. 132 pp 375-388

[3] T. S. Choi, H. C. No, 2010, "Improvement of the reflood model of RELAP5/MOD3.3 based on the assessments against FLECHT-SEASET tests," *Nuclear Engineering and Design* V. 240 pp 832-841

[4] S. C.Yao, L. E. Hochreiter, and W. J. Leech, 1982, "Heat Transfer Augmentation in Rod Bundles Near Grid Spacers," *J. Heat Transf.*, 104, 76