Evaluation on the Conservative Critical Flow Model in SPACE Code using Marviken Test

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1. Introduction

The alpha version of the SPACE code, which is the best-estimate safety analysis code, has been developed, and its verification and validation are in progress. The SBLOCA (Small Break Loss-of-Coolant Accident) evaluation methodology for the APR1400 (Advanced Power Reactor 1400) is also under development using the SPACE code. The goal of the development is to set up a conservative evaluation methodology in accordance with Appendix K of 10CFR50 by the end of 2012. To develop the Appendix K version of the SPACE code, modification of the code is considered through the implementation of the required evaluation models. At present, the Moody model for the conservative prediction of the discharge flow under a two-phase condition is in effect as a look-up table in the SPACE code[1]. In this paper, the implemented conservative critical flow model in the SPACE code is preliminarily assessed against Marviken test.

2. Conservative discharge flow model in the SPACE Code

The critical flow model in the SPACE code was developed based on the Ransom-Trapp (RT) model. However, the Moody model[2] is also implemented into the SPACE code to meet the two-phase discharge flow requirement. Regarding the application of the Moody model, the stagnation condition (p_o, h_o) is derived from the cell center immediately upstream of the exit plane. The stagnation enthalpy can be calculated from the cell center properties as:

$$h_0 = \left(h_f + \frac{v_f^2}{2}\right)(1-x) + \left(h_g + \frac{v_g^2}{2}\right)x \qquad (1)$$

where the local enthalpies(h), fluid velocities(v) and flow quality(x) are evaluated under an equilibrium condition at the cell center. By assuming an isentropic process, the stagnation pressure can then be obtained from the local entropy as defined by the cell center properties and the stagnation enthalpy derived through the steam table iteration:

$$P_o = P_o(h_o, s(h, P)) \qquad (2)$$

The Henry-Fauske model is used for the subcooled liquid condition in conjunction with the Moody model. The discharge flow by this model is also expressed using the stagnation pressure and enthalpy in the SPACE code. Figure 1 presents the discharge flow under both the pressure and enthalpy conditions. This is provided as a look-up table in the SPACE code.

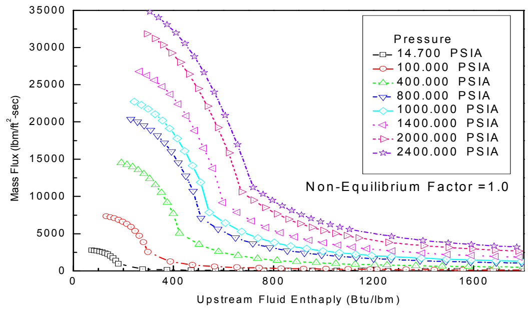


Figure 1. Discharge flow for the combined HF-Moody model in SPACE Code

3. Analysis results

Four representative tests of the Marviken program [3] are used to assess the implementation of the Moody model. These tests include all conditions, such as subcooling, saturated two-phase fluid, and mixture of them. Table 1 shows the boundary conditions for the chosen tests. For the analysis, a discharge coefficient of 1.0 is used as the default.

Table 1. Boundary conditions for Marviken tests

Test conditions	Test 15	Test 20	Test 22	Test 24
Initial upper press. (MPa)	5.04	4.99	4.93	4.96
Subcooling at bottom of vessel (℃)	31	7	52	33
Initial min. temp. (℃)	233	257	211	230
Vessel initial level (m)	19.93	16.65	19.69	19.93
Nozzle L/D (m)	3.6	1.5	1.5	0.3

Figure 2 compares the calculated break flow between the RT model and the HF-Moody model in the SPACE code. The HF-Moody model clearly predicts a higher value than the RT model, ranging from 3,000 kg/sec to 6,000 kg/sec. This range, which appears from approximately 20 to 40 seconds, as presented in Figure 4, is considered as the two-phase fluid regime and is calculated by the Moody model. When the void fraction exists between 0.1 and 0.9, the flow regime is determined as two-phase regime in SPACE Code. It is noted that a two-phase fluid is discharged between 20 and 40 seconds as shown in Figure 3. Thus the conservative approach of the implemented Moody model in a two-phase discharge flow is demonstrated. The behavior of the void fraction is unstable because linear time-smoothing to prevent numerical instability when abruptly switching from one flow regime to another in the SPACE code is not used yet. The code will be modified later.

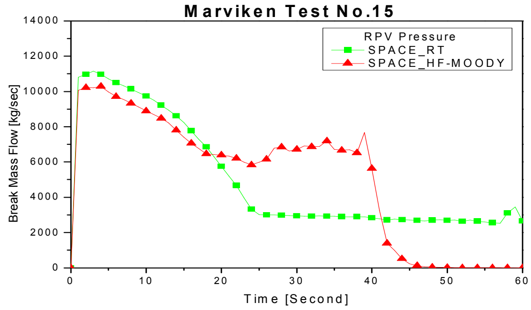


Figure 2. Break flow behaviors for test no. 15

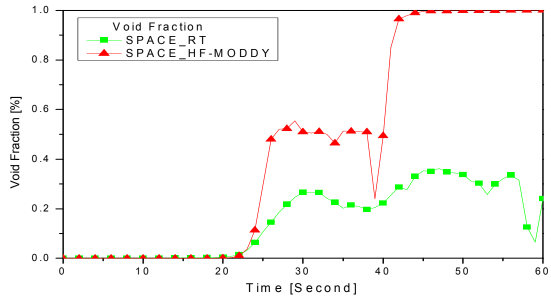
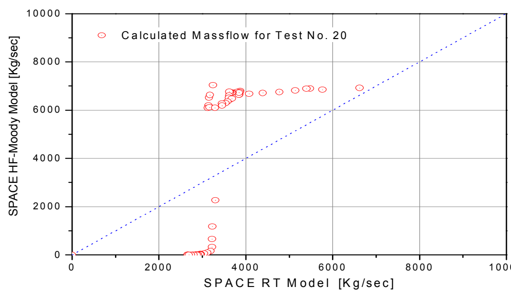
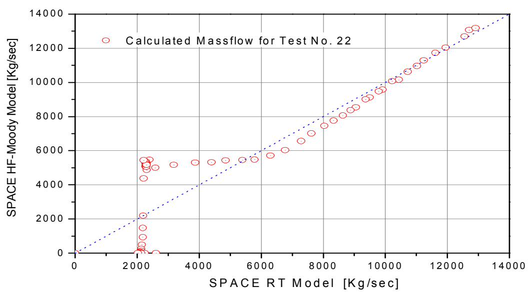


Figure 3. Void behaviors for Marviken test no. 15

Figure 4 compares the calculated break flow between the RT model and the HF-Moody model in the SPACE code for tests no. 20, 22, and 24, respectively. In every case, similar to test no. 15, the HF-Moody model in the SPACE code is conservatively predicted in the two-phase regime.





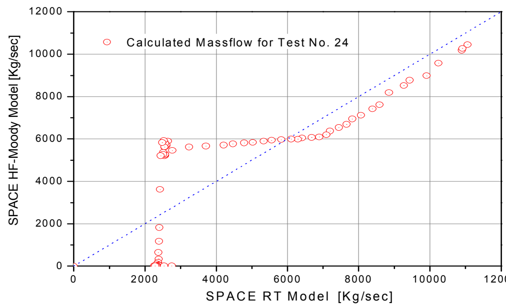


Figure 4. Comparison between RT model and HF-Moody model for test no. 20, 22, and 24

In particular, the water in the pressure vessel of test no. 20 has a subcooling temperature of 7 °C. Thus, most of the water is discharged in a saturated condition. Therefore, the discharged break flow in test no. 20 is calculated by the two-phase critical flow model most of the time, as shown in Figure 4.

4. Conclusion

The Moody model implemented into the SPACE code was preliminarily assessed for a conservative prediction of the discharge flow under a two-phase condition. Although some unphysical behaviors appear as a result of not considering the time-smoothing here, the major results show that the conservative discharge model was successfully implemented into the best-estimate version of the SPACE code.

Acknowledgements

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