Assessment of MARS-KS codes on Counter current flow limiting

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1. Introduction

Counter current flow limiting (CCFL) is an important phenomenon in nuclear reactor safety. Countercurrent flow is defined as the two-phase flow regime in which the working fluids of a system flow with velocities of opposite signs; that is, fluids flowing in opposite directions [1]. During a large break loss of coolant (LBLOCA) accident in pressurized water reactor (PWR), counter current flow of steam and water can be limited due to flooding at high steam flow, which results in water accumulation in upper plenum. Consequently, water accumulation by CCFL reduces the effectiveness of core cooling.

The aim of this study is to validate the MARS-KS code that has been developed for the realistic multi-dimensional system for CCFL phenomenon and presents the comparison of the analysis results between MARS-KS 1.0 and 1.2. Also, MARS-KS code predictions of the Wallis and Kutateladze correlation for the small and large diameter pipe experimental results were evaluated according to correlation factors of the model.

2. Modeling Information

2.1 Marviken Test 24

Marviken Test 24 is the twenty-fourth test in a series of full-scale critical flow tests performed as a multi-national project at the Marviken Power Station in Sweden. The test equipment consisted of four major components: a pressure vessel, a discharge pipe, a test nozzle, and a rupture disc assembly [2].

The vessel was represented by 39 volumes and subdivided from the top as follows: one volume for the top-cupola, one volume for the steam dome, one volume for the two-phase interface region, 36 volumes of equal length (0.5 m) for the main portion of the vessel, and one volume for the bottom of the vessel. The discharge pipe was modeled by six volumes and the nozzle was modeled as a single junction [2].

2.2 Nodalization of CCFL

MARS-KS take the model among the Bankoff CCFL model, and the Wallis and Kutateladze models. In this assessment, Wallis and Kutateladze models were used at each case. The most widely used CCFL correlation is Wallis model and Kutateladze model. The Wallis and Kutateladze model for the small and large diameter pipe respectively defined as follows [3]:

$$j_g^{*1/2} + m_w j_f^{*1/2} = C_w,\ \ j_k^* = j_k \left[\frac{\rho_k}{gD(\rho_f - \rho_g)} \right]^{1/2} \qquad (1)$$

$$k_g^{*1/2} + m_w k_f^{*1/2} = C,\ \ k_k^* = j_k \left[\frac{\rho_k^{\ 2}}{g\sigma(\rho_f - \rho_g)} \right]^{1/4} \qquad (2)$$

where D is the diameter of test section, σ is surface tension, j is the phase superficial velocity, g is the acceleration of gravity and ρ is the density.

Figure 1 shows the nodalization of MARS assessment. It is consist of 5 parts, main pipe, top and bottom vent, air injection, water injection. The test section (pipe) was modeled with a single column and 9 vertical mesh cells as show in Fig. 1. Also, the nozzle was modeled as a single junction with a smooth area change with no special nodalization being used in the nozzle region. In this study, the Wallis correlation factor (C) choose 0.8 and when β=1, Kutateladze correlation factor (C) choose 1.79.

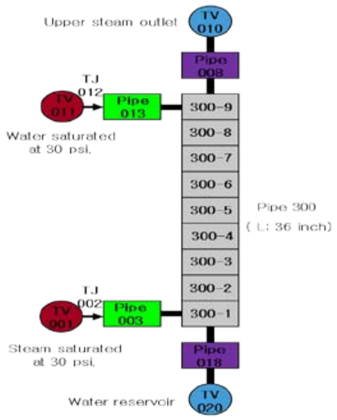

Fig. 1. A nodalization diagram of CCFL single tube test

3. Results

3.1 Comparison According to Code Version

In order to validate the calculation performance between MARS-KS 1.0 and 1.2, the same input model was used. Figure 2 and 3 shows the pressure in the top of the vessel and the measured and calculated mass flow rate at the nozzle for Mariviken Test by using MARS-KS 1.0 and 1.2.

A comparison of the measured and calculated pressure in the top of the vessel shows in Fig. 2. MARS-KS 1.0 and 1.2 calculated the trend of the measured pressure response reasonably well. MARS-KS 1.0 and

1.2 under-calculate the pressure for the first 18 seconds. After 18 seconds, however, MARS-KS 1.0 and 1.2 calculations agreed fairly well with the data until about 35 seconds. The delayed pressure response at the initiation of the transient is caused by the time delay associated with nucleation and subsequent flashing.

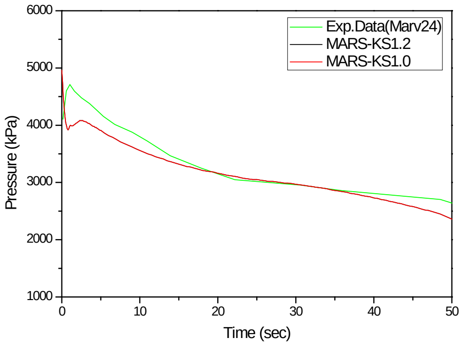

Fig. 2. Measured and calculated pressure in the top of the vessel for Mariviken Test 24

The comparison of calculated and measured nozzle mass flow rate agrees well out to the initiation of two phase flow as shown in Fig.3. After the initiation of two phase flow, MARS-KS 1.0 over-calculated the mass flow rate, whereas MARS-KS 1.2 under-calculated the mass flow rate. Consequently, more mass and energy was expelled from the vessel in the MARS-KS 1.0 calculation. The differences in the calculated mass flow rates seem to be related with the critical flow models used in the two code versions.

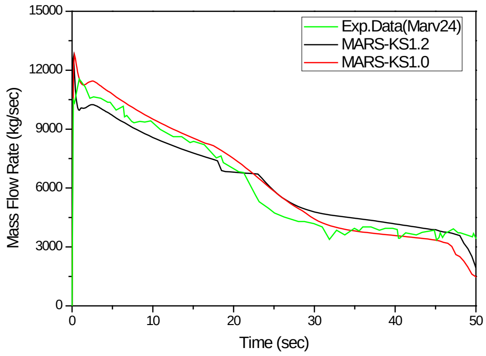

Fig. 3. Measured and calculated mass flow rate at the nozzle for Mariviken Test 24

3.2 Assessment Results of CCFL

In Figure 4, the mass flow rate at each junction was calculated by using MARS-KS 1.2 code that is MARS-KS latest version as the correlation factor was 1.79. At 60 seconds, mass flow rate was fluctuated considerably. That is, CCFL phenomenon occurs at the pipe.

In addition, the mass flow rate at each junction was calculated as shown in Fig.5 by using MARS-KS 1.2 code as the correlation factor was 0.5. MARS-KS 1.2 code accurately not measured CCFL phenomenon because the correlation value was not chosen properly.

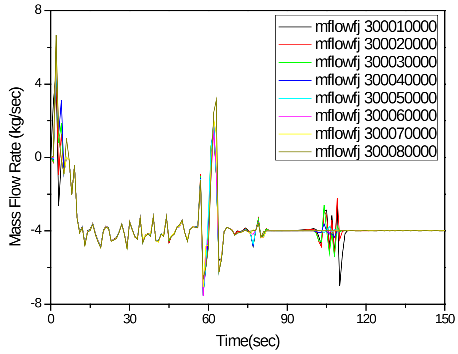

Fig. 4. Calculated mass flow rate at each junction by using MARS-KS 1.2 code(C=1.79)

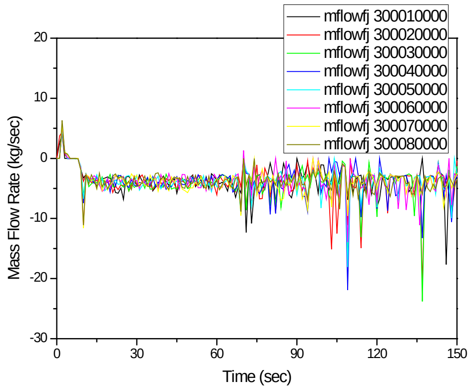

Fig. 5. Calculated mass flow rate at each junction by using MARS-KS 1.2 code(C=0.5)

4. Conclusion

The assessment results and the comparison between the MARS-KS 1.0 and MARS-KS 1.2 codes for the CCFL phenomenon were provided in this paper. MARS-KS results compared well with the Marviken Test 24 data. Consequently, the CCFL model in MARS-KS is working properly. Code modifications to MARS-KS 1.2 have not significantly altered the calculated CCFL behavior. Based on the aforementioned results, the MARS-KS 1.0 can be considered as more conservative than MARS-KS 1.2 for calculating the mass flow rate.

In addition, the correlation factor of the model such as Wallis and Kutateladze models was very important elements for CCFL. Therefore, the correlation factor is chosen properly to accurately assess CCFL phenomenon.

REFERENCES

[1] Counter current flow limitation experiments and modeling for improved reactor safety, Texas A&M University, Jun 2008.
[2] MARS Assessment Manual, KAERI, Dec 2009.
[3] TRACE V 5.0 User's Manual Volume 1: Input Specification, U. S. Nuclear Regulatory Commission.