Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-19, 2017

Uncertainty Estimation of Henry-Fauske Critical Flow Model Considering Thermal-nonequilibrium Constant and Discharge Coefficient in MARS-KS

Il S. Lee*, Young S. Bang, Deog Y. Oh, Byung S. Kim, Suk H. Lee, Jeong Y. Kim, Chae Y. Yang
Safety Assessment Dept., Korea Institute of Nuclear Safety, 62 Gwahak-ro, Yuseong, Daejeon, Korea, 305-338
**Corresponding author:islee@kins.re.kr*

1. Introduction

It is very important to evaluate critical flow in the safety assessment such as LOCA, MSLB etc. There are several models (HEM; Homogeneous Equilibrium Model, HFM; Homogeneous Frozen Model, Ransom Trapp, Henry Fauske Model) to simulate the critical flow in computer codes to analyze safety of the nuclear power plants. The default critical flow model in MARS-KS 1.4 [1] used by KINS as independent regulatory assessment is the Henry-Fauske model, it is important to consider that the actual vapor quality is below the equilibrium quality due to thermal-nonequilibrium. The use of the Henry-Fauske critical flow model in MARS-KS code is required of specifying for two adjustable coefficients, the traditional discharge coefficient (C_d) and a thermal-nonequilibrium constant (N_{eq}), to provide the analyst with the means to better characterize the break. So this paper focuses on estimation of the uncertainty of Henry-Fauske critical model by variety of both N_{eq} and C_d using experimental data of Marviken CFT-15 and 24 [2].

2. Henry-Fauske critical flow model

The expression for the critical value of the mass flux in MARS-KS is

$$G_c^2 = \left\{ \frac{x_0 v_v}{\eta P} + \left(v_v - v_{l,0}\right)\left[\frac{(1-x_0)N}{(s_{v,eq}-s_{l,eq})}\frac{ds_{l,eq}}{dP} - \frac{x_0 C_{p,v}(1/\eta - 1/\gamma)}{P_t(s_{v,0}-s_{l,0})}\right]\right\}^{-1}$$

If the thermal-nonequilibrium factor, N, is taken to be unity, the prediction of equation is close to that of the homogeneous equilibrium model, and if N equals zero the solution is approximately the homogeneous frozen model. Therefore the quantity N attempts to correlate the partial phase change occurring at the throat.

The parameter which is called as discharge coefficient is used to relate the results for an actual nozzle to an "ideal" nozzle represented by the model. In the MARS-KS default critical flow model, only one value of the discharge coefficient can be specified for each junction. This single value is unconditionally applied to the critical mass flux whatever the upstream conditions are subcooled liquid, two phase, or single phase vapor. As discussed above, allowing the user to only one value per junction maintains the continuity of the critical flow solution across phase boundaries without the need to resort to the use of smoothing functions.

In this paper, uncertainty of Henry-Fauske model is considered by two parameter, discharge coefficient and thermal-nonquilibrium constant, and it is determined by using large scale Marviken experimental data. Figure 1 shows schematic diagram of large scale Marviken and its nodalization. Table 1 is initial condition of CFT 15 and CFT 24, respectively.

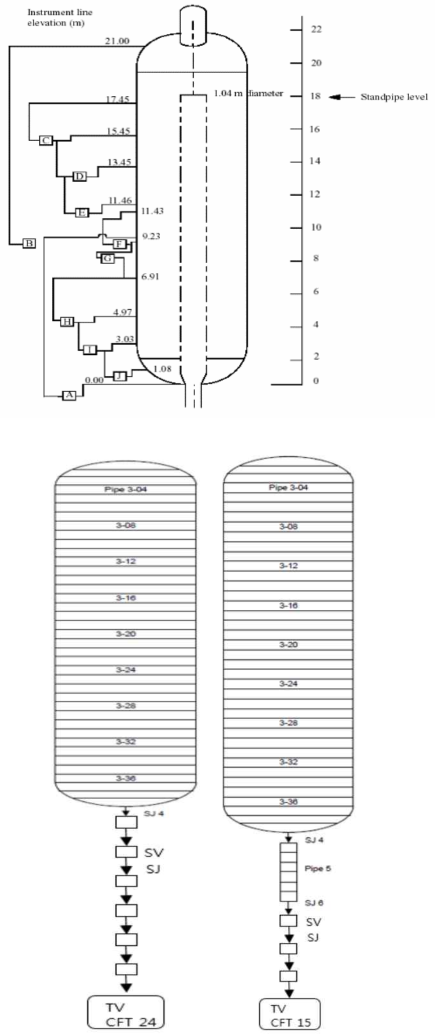

Fig. 1 Marviken facility and nodalization

3. Results of critical mass flow rate depending on discharge coefficient

Figures 2 and 3 show critical mass flow rates calculated by MARS-KS depending on discharge coefficient. Especially, representation was made in terms of mass flow rate versus pressure, which is more comparable with the original Henry-Fauske model and may exclude an additional source of inaccuracy by time interval.

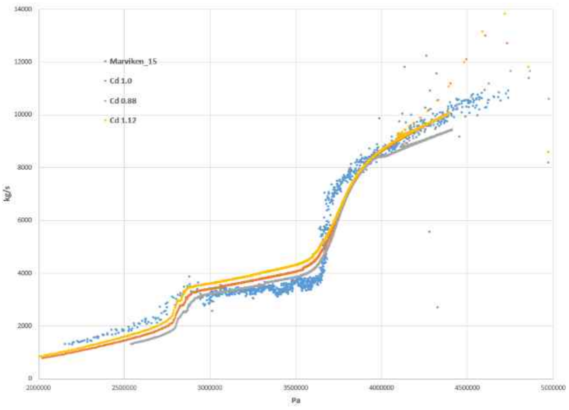

Fig. 2. Results of critical mass flow rate in CFT-15(Cd)

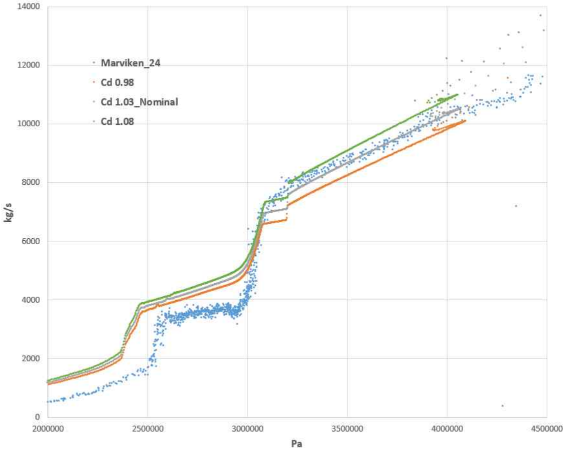

Fig. 3. Results of critical mass flow rate in CFT-24(Cd)

As you can see, there is small difference in the single liquid region and there is a difference in the discharge coefficient variation in two phase region on CFT-15. It can't be predicted well and the distortion is severe when discharge coefficient is lower than 0.88. In contrast to CFT-15, CFT-24 shows the somewhat difference from single liquid region and as with the CFT-15 calculation results, the higher the discharge coefficient, the more critical mass flow rate over the entire time(60sec) but the later deviation becomes larger.

4. Results of critical mass flow rate depending on thermal-nonequilibrium

Figures 4 and 5 are critical mass flow rate calculated by MARS-KS depending on thermal-nonequilibrium according to pressure at entrance of nozzle in CFT-15 and CFT-24, respectively.

In Figure 4 and 5, it can be seen that the total critical flow rate increases as the thermal non-equilibrium constant increases. In Figure 4, it can be seen that the thermal non-equilibrium factor does not affect to critical mass flow rate in the single phase region but little affects only two phase region. The reason is that the long nozzle has a sufficient time to reach the thermal equilibrium between the liquid and the vapor with a relatively long nozzle (L / D = 3.6), so that the influence on the thermal non-equilibrium factor is small.

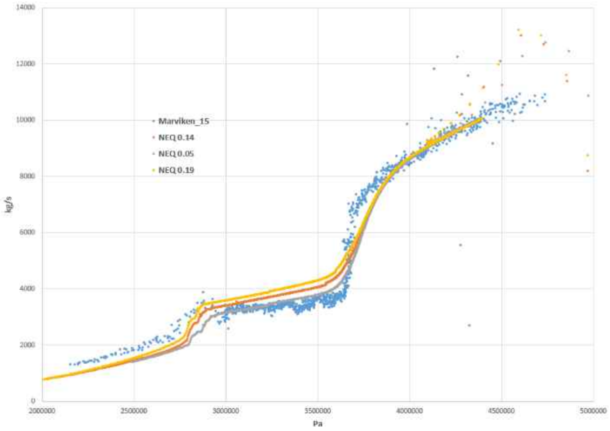

Fig. 4. Results of critical mass flow rate in CFT-15(Neq)

Figure 5 shows that the variation of the thermal-nonequilibrium influences to critical mass flow rate from the single liquid region. This is because the short nozzle (L/D=0.3) doesn't have enough time to reach the thermal equilibrium between the liquid and the vapor, so that the influence of the thermal non-equilibrium factor is large from liquid region. The figure clearly indicates that the test data can be covered by the MARS calculation with the range of N_{eq} (0.1~0.3) until 3.1 MPa. Also below the the prssure, MARS calculation shows over prediction of discharged mass flow rate regardless of N_{eq}.

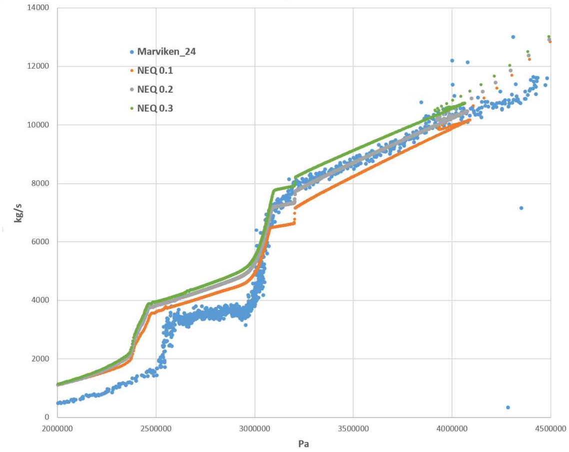

Fig. 5. Results of critical mass flow rate in CFT-24(Neq)

5. Conclusion

Based on the Marviken experiment CFT-15 and 24 data, the uncertainty of Henry-Fauske critical flow model was evaluated. For the long nozzle (CFT-15, L/D=3.6), there was no range of uncertainty in the MARS-KS that could cover experimental data depending on the discharge coefficient and thermal non-equilibrium constant. In the case of the short nozzle (CFT-24, L/D=0.3), the uncertainty range of discharge coefficient 0.98 ~ 1.08 was derived for the region where the nozzle inlet pressure was greater than 3.3 MPa and the uncertainty range of thermal-nonequilibrium 0.1 ~ 0.3 was derived for the region above 3.1 MPa.

REFERENCES

[1] KAERI, MARS code manual, KAERI/TR-3872, 2009.
[2] The Marviken Full Scale Critical Flow Tests report, "Summary report. MXC-301", December 1979.
[2] Salomon Levy, Two phase flow in complex systems, John willey & Sons, Inc, 1999.
[3] Akihiko Minato et al, Numerical study of two dimensional structure in critical steam-water two phase flow, Journal of Nuclear Science and Technology, Vol. 32, pp464~475, 1995.

ACKNOWLEGEMENT

This work was supported by the Nuclear Safety Research Program through the Korea Foundation of Nuclear Safety (KOFONS), granted financial resource from the Nuclear Safety and Security Commission (NSSC), Republic of Korea (No. 1305002).