Comparison of Different Safety Injection Tank Models in MARS-KS

Jai Oan Cho [a], Jeong Ik Lee [a]*, Young Seok Bang[b], Seung Hun Yoo[b]
[a]*Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology (KAIST)*
[b]*Safety Evaluation Department, Korea Institute of Nuclear Safety (KINS)*
Corresponding author: jeongiklee@kaist.ac.kr

1. Introduction

The Advanced Power Reactor (APR) 1400 has an emergency core cooling system (ECCS). One of the most important components in the ECCS is the safety injection tank (SIT). Inside the SIT, a fluidic device (FD) is installed, which passively controls the mass flow of the safety injection of the coolant, eliminating the need for low-pressure safety injection pumps. As passive safety mechanisms are emphasized nowadays, it has become more important to model the SITs more realistically.

As shown in Fig. 1, during the high flow mode, water level is higher than the standpipe height. Hence, water flows into the vortex chamber of the FD from two ports, the supply port and the control port. Water from the two different nozzles collide and flows into the discharge pipe directly. During the low flow mode, water level is lower than the standpipe height, therefore, water can only flow into the vortex chamber through the control port. Therefore, the flow is directed to a tangential angle of the vortex chamber generating a vortex, resulting in a lower water flowrate supplied to the reactor core. [1]

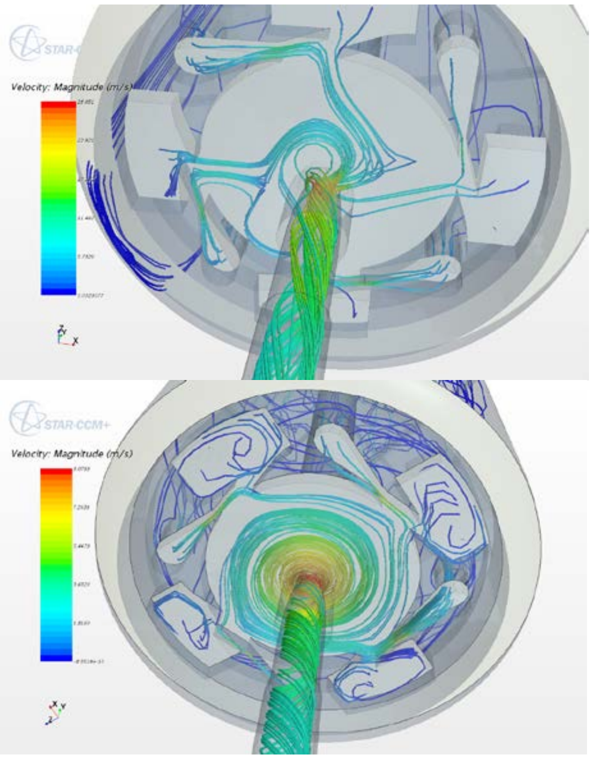

Fig. 1. Streamlines within the FD during high flow (top) and low flow (bottom)

1D system codes, such as MARS-KS, have used single or double k-factors to control the mass flow of SITs. However, in the real case, the k-factor and mass flow may be not a constant. Moreover, as the water level drops, nitrogen may be entrained into the discharge pipe and then into the core. This may affect the core cooling capability and threaten the fuel integrity during LOCA situations. However, information on the nitrogen flow rate during discharge is very limited due to the associated experimental measurement difficulties, and these phenomena are hardly reflected in current 1D system codes. This study focuses on determining the pressure loss coefficient more accurately which will make the results more reliable prediction of SIT performance and uncertainty range to be considered.

2. MARS-KS Modeling

The safety injection tank was conventionally modeled with the accumulator model implemented in the code itself [2]. However, newer safety injection tanks like those installed in the APR1400 have fluidic devices that can control mass flow depending on the water level height. Accumulator models need two different valves with two different pressure loss coefficients to simulate the different mass flows. In addition, the implementation of fluidic device introduced nitrogen entrainment into the system, which cannot be simulated with the accumulator model.

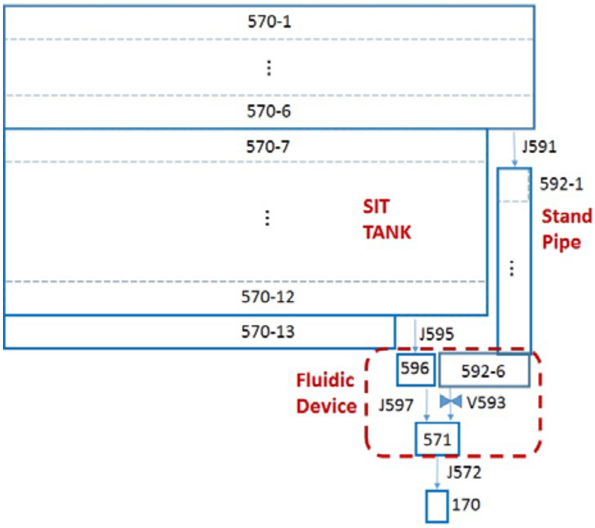

Fig. 2. Nodalization of the SIT pipe model

Therefore another model was developed using pipe and junction components [3]. The nodalization is shown in Fig. 2. The new pipe model includes a standpipe and a fluidic device. In addition, a valve is situated where the flow from the supply port meets with that of the control port. It cuts off excessive nitrogen entrainment through the standpipe once the standpipe is emptied. Previous studies show that such modeling makes pressure and mass flow prediction much more accurate. Unlike the accumulator model, the pressure loss coefficient is given in two different places (V593 J597).

This study focuses on modeling the pressure loss coefficient of the supply port and control port more accurately. The pressure loss coefficients were tuned in components J597 and V593. Three different models were used for comparison using different methods to determine the pressure loss coefficients.

The first model (SIT_A) uses pressure loss coefficients based on CFD calculations. The authors have done prior CFD calculations of the SIT [1]. We can extract the mass flow from each of the flow paths through CFD calculation. Based on the calculation result, pressure loss coefficients were calculated based on the mass flow and the flow area of the supply port and control port respectively. K_{597} and K_{593} were calculated to be 10 and 45 respectively.

The second model (SIT_B) uses experiment data to find a constant for the pressure loss coefficient. The test data came from Shin-Kori Unit 3 SIT cold function test. Since the data did not come from an experimental facility, the only data available for an SIT performance test were the pressure and water level. For a direct comparison, the water level slope was compared to match the mass flow rate. The high flow mode requires two values of pressure loss coefficient while the low flow mode requires only one coefficient. Therefore, the slope during the low flow mode was compared first to acquire the pressure loss coefficient for the control port. Then the slope during the high flow mode was compared to obtain the pressure loss coefficient for the supply port. K_{597} and K_{593} were found to be 24.5 and 500 respectively.

The third model (SIT_C) uses the built-in function for the pressure loss coefficient based on the Reynolds number using eqn. (1). A wide range of constants were set for each of the parameters and for each of the ports. Six parameters were given a range and samples retrieved by Latin Hypercube Sampling (LHS) were tested. LHS allows effective sampling when many variables are introduced. Testing the model with different sample sets, we were able to compare the results with the test data to find the set that gives the closest result with those of the experiment. The set is shown in Table II.

$$K = C_1 + C_2 \times Re^{-C_3} \quad (1)$$

Table I: Range of each variable for pressure loss coefficient function

	Supply Port	Control Port
C_1	50 - 150	11.0 – 19.0
C_2	1.5E11 – 9.0E11	2.0E11 – 8.0E11
C_3	1.63 – 1.77	2.6 – 3.0

Table II: Value of each variable for pressure loss coefficient function

	Supply Port	Control Port
C_1	36	18
C_2	7.42 E11	8.32 E11
C_3	1.75	2.56

The dominant variable was different in the supply port and control port. In case of the supply port, the dominant variable was C_2 and C_3. On the other hand, C_1 was the dominant variable in the control port. This is because the pressure loss coefficient is a function of Reynolds number and the Reynolds number is significantly higher in the supply port.

3. Results & Comparison

We can plot the mass flow rate from each model and compare it with the results from the experiment. The graphs below show the calculated mass flow rate plotted against the experimental data.

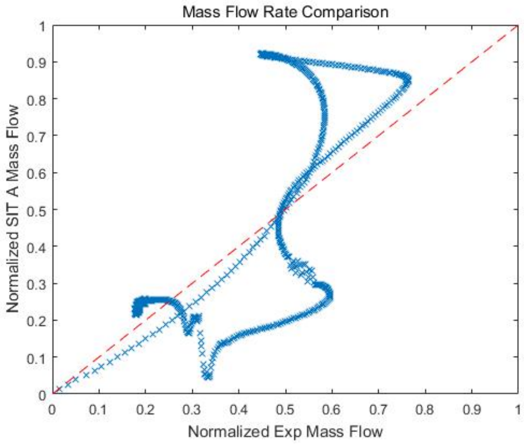

Fig. 3. Mass Flow Rate of model SIT_A and experiment

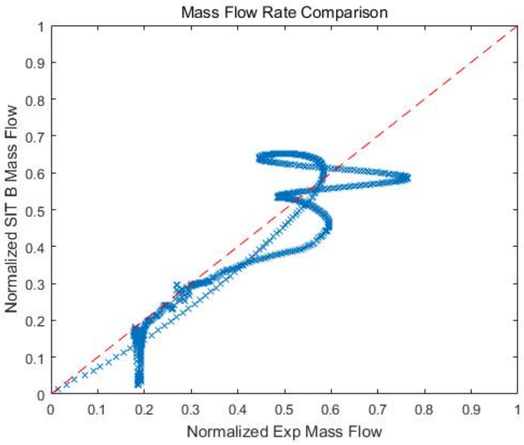

Fig. 4. Mass Flow Rate of model SIT_B and experiment

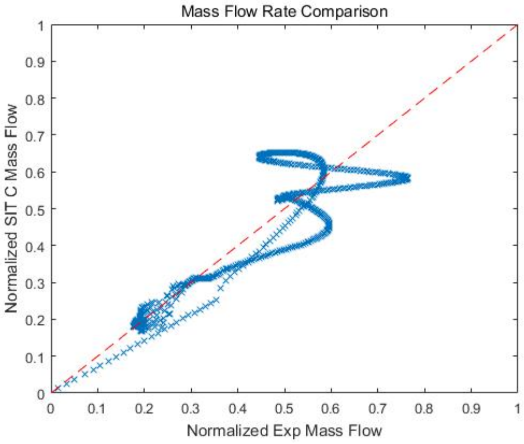

Fig. 5. Mass Flow Rate of model SIT_C and experiment

When we plot the mass flow rates of each model in one graph we can clearly see that the model SIT_C has the best results.

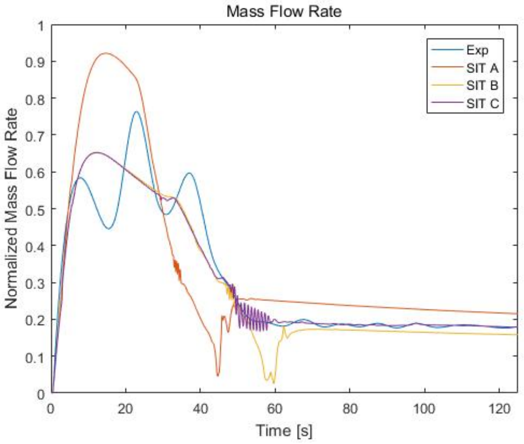

Fig. 6. Comparison of Mass Flow Rate of different models

We can quantify the deviation from the experimental value using the R^2 value. If we call y_i values the data sets, f_i values the reference value, and $\bar{y}$ the mean value of the data sets, we can define eq. (2) and (3), which can be used to define R^2 by eq. (4). Table III shows the R^2 value for each case. The closer the number is to 1, the closer it is to the experimental result. Just as we anticipated, SIT_C model is closest to the test data and is the most suitable for modeling the SIT tank.

$$SS_{res} = \sum_i (y_i - f_i)^2 \quad (2)$$

$$SS_{tot} = \sum_i (y_i - \bar{y})^2 \quad (3)$$

$$R^2 = 1 - \frac{SS_{res}}{SS_{tot}} \quad (4)$$

Table III: R^2 value of each model

Model	SIT_A	SIT_B	SIT_C
R^2	0.5596	0.8628	0.8671

4. Conclusion

Several models of the SIT were compared to find the most suitable one for a system analysis. Among the three models compared, SIT_C model showed the best performance. The SIT_B model showed very close performance but had some deviation from the experiment data during the transition from the high flow to the low flow. Thus, in future modeling of the SIT with FD, K-factor as a function of Reynolds number is recommended to be used for the calculation of the related accident.

ACKNOWLEDGEMENTS

Authors gratefully acknowledge that this project is funded by the KUSTAR-KAIST Institute joint research project.

REFERENCES

[1] J. Cho et al., Computational Study of the Safety Injection Tank Performance, CFD4NRS6, Sep. 13-15, 2016, MIT, Cambridge, MA, USA

[2] KHNP, Final Safety Analysis Report Shinkori Units 3& 4, 2015.

[3] Young S. Bang, et al, Hydrodynamics of Safety Injection Tank with Fluidic Device in Recent Regulation, KNS Autumn Meeting, 2016