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Development and Verification of Siphon Breaker Simulation Program

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1. Introduction

Some research reactors are applied to plate-type fuel, such as JRTR (Jordan Research and Training Reactor) and KJRR (KIJANG Research Reactor). In this cases, the research reactor requires core downward flow. However, if pipe rupture occurs in the primary cooling system with a lower position than the reactor, the siphon effect steadily drains water out which could result in the exposure of the reactor core to the air. For this reason, a safety facility is necessary, and the siphon breaker is one of facility to prevent LOCA (Loss of Coolant Accident).

To investigate the effect of siphon breaker on research reactor, real-scale verification experiments were performed by POSTECH (Pohang University of Science and Technology) and KAERI (Korea Atomic Energy Research Institute).[1,2] From the experiment results, a theoretical model was established. Furthermore, to analyze the siphon breaking phenomenon and to design the siphon breaker easily, the simulation program which has a GUI type was developed. Theoretical model, simulation program, and the representative results are presented.

2. Theoretical Model for Siphon Breaking

2.1 Loss of coolant calculation

Before the exposure of siphon breaker entrance, the coolant leaks out, and it could be described as single-phase flow. At first, a velocity of fluid can be derived from Bernoulli's equation. Next, a volumetric flow rate can be derived by multiplying the velocity by area. Finally, water level can be calculated from the volumetric flow rate.

2.2 Siphon breaking calculation

Like as loss of coolant calculation, basically, siphon breaking calculation also gets the value of velocity, volumetric flow rate, and water level from Bernoulli's equation. However, since the siphon breaking phenomenon is two-phase flow, there are additional points to be considered. Representative consideration is two-phase flow model and to choose the two-phase flow analysis model, an accuracy verification test was performed. Chisholm model was more accurate than homogenous model, we tried to analyze the two-phase flow with Chisholm.[3]

In Chisholm model, a coefficient B was included and it alters with mass flow. Ultimately, derivation of correlation formula between coefficient B and reactor design conditions is significant point of theoretical model.

At first, it is necessary to adjust pressure loss coefficient to the correct value according to the experimental conditions. Therefore, friction loss and form loss, for example, experimental configuration included sudden expansion are considered. After fine tuning of pressure loss coefficient, the value of Chisholm coefficient B was altered repeatedly until the undershooting height value of the simulation was equal to that of the experiment. (Undershooting height indicates how much the water level decreased during the siphon breaking) After trial and error process, Chisholm coefficient B could be deduced. Because the mass flow of air and water need to be considered when setting the value of Chisholm coefficient B, a criterion to evaluate the mass flow quantitatively are necessary. As a result, by using air flow rate factor[4] and mass flux of water, the criterion which can evaluate the two-phase flow. The criterion called C factor, and we try to deduce the relation between C factor and Chisholm coefficient B. In order to find the relation, regression analysis was used. As a result, two type of correlation formulas (Exponential and Quadratic function) could be derived and R^2 values were 0.93 (Exponential function) and 0.97(Quadratic function).[5]

The graph comparing the simulation and experimental results with percentage error is shown in Fig. 1. The Chisholm model, which is applied to derive the Chisholm coefficient B from the C factor, has approximately around 10% error. Therefore, the theoretical model and the correlation formula were useful for analyzing siphon breaking.

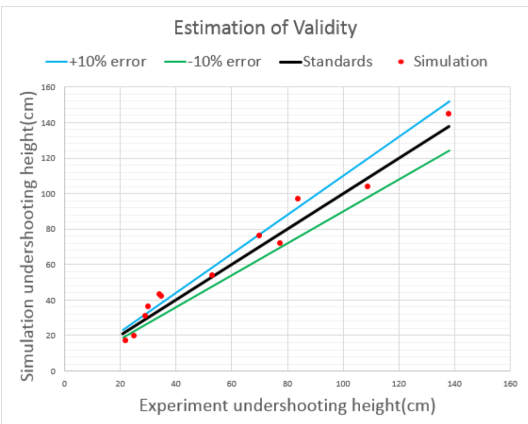

Fig. 1. Estimation of Validity

3. Siphon Breaker Simulation Program(SBSP)

The simulation program was developed using MFC (Microsoft Foundation Class) programming method.[6] The program included the theoretical model for analysis. Program algorithm is shown in Fig. 2. At first, after opening the program, the user enters the input parameters. Next, the user operates the calculation process, and the program performs the 3-stpes calculation by substituting the input parameters into the included theoretical model. Step 1 is the calculation for loss of coolant, step 2 is siphon breaking process, and step 3 is steady state calculation. The results can be expressed with various ways. Fig. 3 is the graph was provided by simulation program. Not only graph, but also data save function is provided also. Fig. 4 is a graph showing the change of flow rate according to time for SBL (Siphon Breaker Line) sizes of 2.5in and 3in. When the SBL size was larger, the flow rate was lower and the time until completion was reduced. The program predicted this trend accurately, and the simulated flow rate was similar to the experimental values. However, there are some errors between experiment and simulation at the beginning. Actually, the flow rate evaluation of experiment in the beginning phase was based on the visualization video, and the flow rate data of experiment were calculated from the water level changes for 5 second intervals. This method was an alternative way because the ultrasonic flowmeter couldn't measure the flow rate accurately before the fully developed flow. The difference between experiment and simulation occurred at the beginning phase seems to be due to this point.

4. Application

The theoretical model and SBSP could be analyze the siphon breaking and design the siphon breaker.

4.1 The effect of changing the entrance of SBL

Siphon breaking is influenced by various design condition. This simulation is to find out the effect of the entrance position of SBL. Simulation results and experiment results are shown by Table 1.[1] The simulation results show that the undershooting height increased or decreased according to position. However, the final water level was always constant. That is, changing the entrance position of the SBL did not seem to affect the final water level. Similarly, the experimental final water levels were the same for the five cases in Table 1. Therefore, the simulation program was able to calculate the results well, according to the given conditions, in particular the SBL entrance positions.

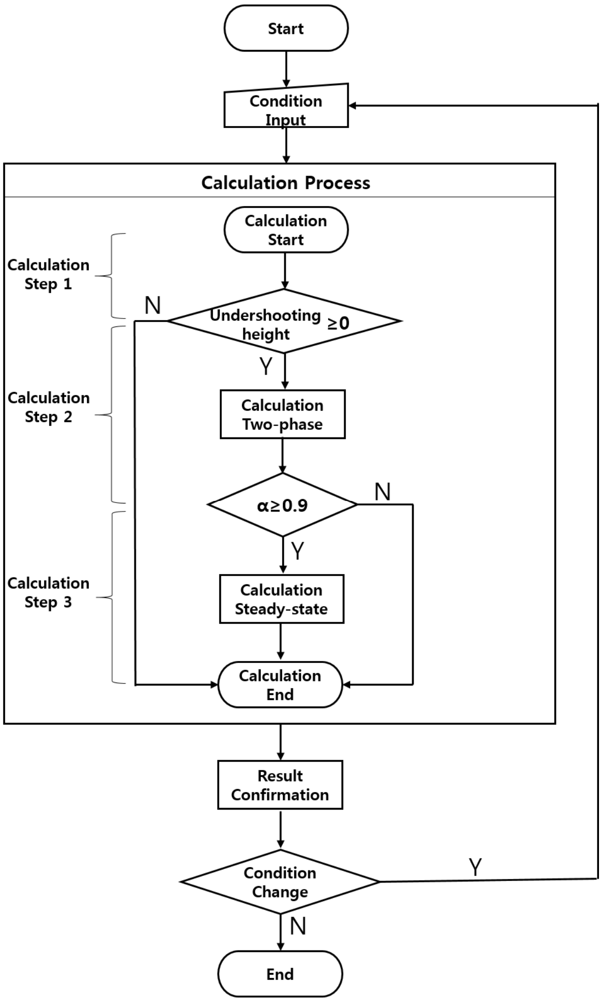

Fig. 2. SBSP Algorithm

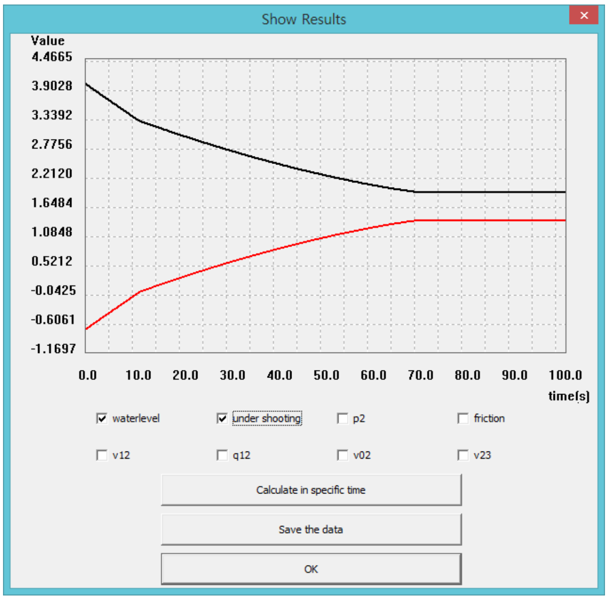

Fig. 3. Simulation Result

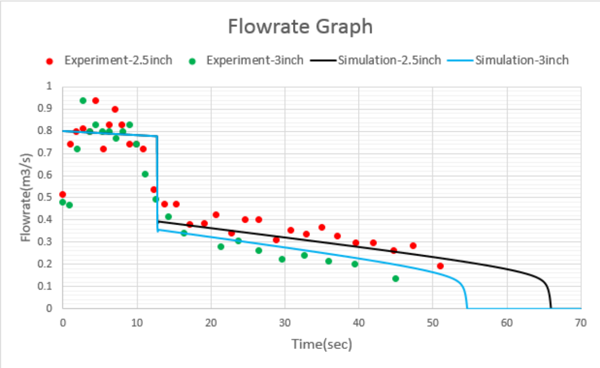

Fig. 4. Flowrate Graph

Table 1. Changing he Entrance of SBL Results

	Position 0	Position 2	Under-Shooting (cm)	Water Level (cm)
Sim	350	330	85	265
Exp			92	258
Sim	340		75	265
Exp			79	258
Sim	330		65	265
Exp			70	259
Sim	320		55	265
Exp			63	258
Sim	310		45	265
Exp			53	258

Sim : Simulation   Exp : Experiment

Table 2. Changing the Tank Area Results

	Area (m^2)	Undershooting (cm)	Time (s)
Default × 1	14.22	44.76	40.25
Default × 1.5	21.33	44.43	59.9
Default × 2	28.44	44.24	79.6
Default × 2.5	35.55	44.11	99.15
Default × 3	42.66	44.02	118.7

4.2 The effect of changing the tank area

This simulation is to find out the effect of the tank area. Default value of tank area is 14.22m^2. Under the same conditions (16in LOCA, 4in SBL), except the tank area, simulations were performed and the results are shown by Table 2. According to tank area increase, undershooting height value shows a marginal decrease. That is, tank area does not affect the undershooting results. However, according to tank area increase, time to complete the siphon breaking is also increase. In other words, increasing the tank area can be negligible in view of undershooting, but it is effective in delaying water efflux.

4.3 Siphon breaker design

It is possible to use the theoretical model to easily determine the design conditions, which satisfy the safety requirements. For example, assuming that complete pipe rupture occurs, with a main pipe of 16 in. and larger, the size of SBL for safe undershooting height can be determined. Because the water level lowers basically as the radius of the main pipe decreases, for main pipes of 16in, 18in, and 20in, the safety requirements are decided as 20cm, 23cm, and 25cm respectively.

The simulation results are shown in Fig. 5, if the SBL size was 4in, the safety requirements were no met because the values were too far above the safety requirements for undershooting height. Therefore, a SBL of size 4in. is to be avoided to ensure safety. In the case of an SBL of size 5in., the safety conditions for a 16in. main pipe were met. However, for main pipe sizes greater than 16in., the design is still unsafe. In the case of a 6 in. SBL, the exposure of the core was prevented in all cases.

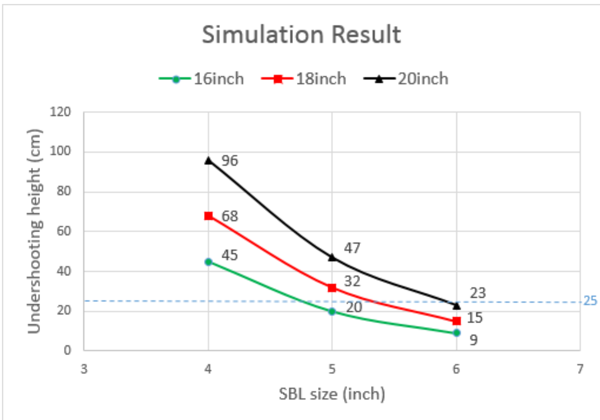

Fig. 5. Siphon Breaker Design

5. Conclusions

The theoretical model based on fluid dynamics and Chisholm model for siphon breaking phenomenon was developed. Specially, a correlation formula was proposed for the Chisholm coefficient B, which is generally applicable to two-phase flow.

When the simulation results were compared with the experimental results, it was shown that the program could analyze the real siphon breaking phenomenon and predict the progress of breaking in terms of the time, with results closely approximating to those in an actual situation.

In conclusion, SBSP can assist with the analysis of siphon breaking and with the design of the siphon breaker.

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