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SPACE3.0 and RELAP5/MOD3.3 Simulations of Siphon Break Experiments

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1. Introduction

The system codes used for the safety analysis of reactor facilities should accurately and reliably predict the transient phenomena for the facility. Therefore, it is necessary to have appropriate model and analysis capabilities for the purpose, the range, and the major thermal hydraulic phenomena of the facility. Most of the existing safety analysis codes have been developed for the safety analysis of nuclear power plants. A number of verification and validation ensure the accurate performance and reliability of the system codes.

In addition, these codes have been used after numerous evaluations to determine whether safety analysis capabilities are appropriate for research reactors. The RELAP5 was widely used for safety analysis of various research reactors (OPAL in Australian & NBSR, ATR, HFIR in US), and other RETRAN and CATHENA codes were also used for the safety analysis of research reactors.

The SPACE is a system code developed for the safety analysis of nuclear power plants. This code was developed by Korea Hydro & Nuclear Power Co., KEPCO Engineering & Construction Co., and Korea Atomic Energy Research Institute. If the applicability of the code to the research reactor is validated, the SPACE code can be used for the safety analysis of research reactors.

It is essential to evaluate whether the SPACE code well predicts thermal hydrodynamic phenomena in research reactors with different operating conditions such as relatively low temperature and low pressure and nuclear fuel. Thus, we are studying whether the SPACE code can be applicable to the safety analysis of research reactors.

In this paper, we carried out the analysis of the anti-siphon phenomenon among various phenomena that occur in research reactors. Pool water plays a very important role as a final heat sink for most pool-type research reactors. Therefore, one of design criteria for the reactors is that the water level of reactor pool must not decrease below a predefined elevation even against the most severe accident due to ruptures of coolant boundary of connecting systems to the reactor pool. When a pipe rupture occurs, the pool level steadily decreases below the reactor core by the siphon phenomenon. To prevent this and meet the design criterion, siphon break devices are installed in the research reactors.

Many experiments were carried out to understand the thermal hydraulic characteristics of siphon break. Full-scale experiments have been performed by POSTECH in various sizes of pipe rupture and siphon breaker line [1]. A series of experiments has been conducted by Idaho state university in an experimental facility consisting of relatively small size pipe [2].

In this paper, SPACE3.0 and RELAP5/MOD3.3 were used to simulate the experimental data. Their calculation results were compared with the experimental data.

2. Siphon Break Experiment of POSTECH

2.1 Modeling of the Experiment

Figure 1 presents a schematic diagram of nodalization for siphon break experiment. The main components of the facility are a upper tank (110 to 140), 16-inch main pipe (200 to 250), siphon breaker line (410 to 440), discharge line (270, 272, 274, 280), and butterfly valve (271). The valve of 14 inches was determined to simulate a loss of coolant accident (LOCA). At time of zero, the transient would be started by opening this valve. The siphon breaker line was filled with water at the initial state and air enters when water level goes down below the inlet of node 410. Node 310, 320, and 330 modeled the atmospheric condition with TFBCs.

2.2 Prediction of Experiment without Siphon Breaker

Loss coefficients of piping and valve were determined based on a single phase experiment without a siphon breaker line. After a pre-calculation, the pool level, the flow rate at the discharge line, and the differential pressure at the longest vertical pipes were compared with the experimental data. And the loss coefficients were adjusted to correct the difference between the prediction and the experiment. All parameters predicted by both SPACE3.0 and RELAP5/MOD3.3 were in good agreement with those measured. The determined loss coefficients were applied to the calculations of the siphon breaker experiments.

2.3 Results of Siphon Break Experiments

Figure 2 shows the prediction of pool level in a 14-inch LOCA with a 4-inch siphon breaker during transient. Both SPACE3.0 and RELAP5/MOD3.3 evaluate the pool level lower than the experiment when the siphon is blocked, and SPACE3.0 predicts much lower pool level than RELAP5/MOD3.3. The water flow path of the main pipe connected to the siphon breaker line is reduced by the inflow of air through the siphon breaker line. In this region, the flow rate of water is continuously suppressed with the lapse of time and the discharge flow rate decreases and then disappears. As a result, the pool level remains constant. From the calculated results, the system codes show a slight lack of performance in predicting this phenomenon. Therefore, it seems necessary to modify the flow pattern map or to develop a component model in order to predict the phenomena well.

Figure 3 shows the trend of pool level in a 14-inch LOCA with a 6-inch siphon breaker during transient. In this case, the results of two system codes are in good agreement with the experimental data. As the size of the siphon breaker line increases, the amount of air inflow increases and the flow resistance at the connection part between the siphon breaker and the main pipe is greatly increased. This reduces the inertia of the water flow in the main pipe including that connection part. As a result, the discharge flow rate is reduced more rapidly than that of the 4-inch siphon breaker. The siphon breaking of 6-inch siphon breaker is relatively well predicted.

3. Siphon Break Experiment of Idaho State Univ.

3.1 Modeling of the Experiment

Figure 4 shows the node diagram used to model the experimental facility. The main components of the experimental facility are a 500-gallon upper tank (110), 4-inch siphon upcomer (140), apex (146, 150), downcomer (160) pipes, and a lower catch tank (200). A 3-inch PVC pipe (120, 130) connects the outlet from the bottom of the upper tank to the upcomer and contains a turbine flow meter. A 4-inch PVC (160, 170, 180) pipe connects the outlet of the downcomer to the catch tank. A 0.75-inch anti-siphon air line (510, 520, 530) is connected at the top center of the apex of 30-inch long. The air line contains a turbine flow meter. Orifices (515, 185) are equipped at the inlet of the air line and the outlet of the discharge line.

In the experimental study [2], siphon tests with various orifice sizes were performed and water volume of the upper tank, water flow, air flow, and gauge pressures at the apex and the discharge pipe upstream of the outlet orifice were measured.

3.2 Prediction of Single Phase Experiment

In order to compare the prediction of the codes with the results of a single phase experiment carried out with the ball valve (525) closed as shown in Figure 3, the water volume of the upper tank, the flow rate of water, and the differential pressures at the apex and discharge outlet orifice were first calculated. The loss coefficient of the discharge outlet orifice was then adjusted to correct a little difference between the prediction and experiment values. All of the parameters predicted by both SPACE3.0 and RELAP5/Mod3.3 show a good agreement with those measured. The adjusted loss coefficient of the orifice is used for all calculations to predict the siphon tests performed with the same discharge outlet orifice.

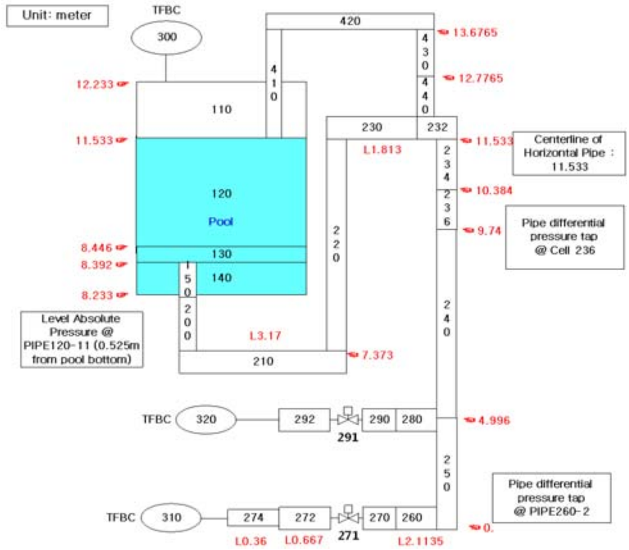

Fig. 1. Modeling of the POSTECH experimental facility

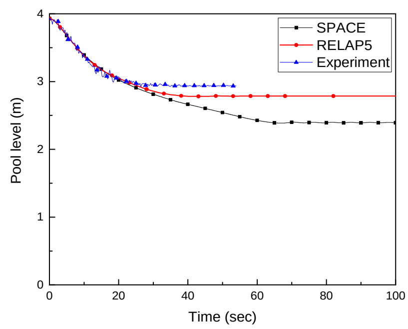

Fig. 2. Prediction of pool level in 14-inch LOCA with 4-inch siphon breaker.

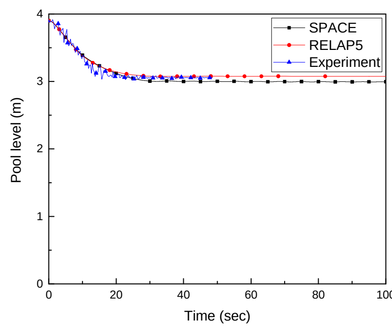

Fig. 3. Prediction of pool level in 14-inch LOCA with 6-inch siphon breaker.

3.3 Results of Siphon Break Experiment

Figure 5 shows the results of the water volume during transient with the conditions that the air line and the discharge line have an orifice size of 3.45 mm and 21.13 mm, respectively. The predictions of the two codes show a good agreement with the experimental results. After around 50 seconds, the rate of decrease of the water volume slows down.

Figure 6 shows the results of the water flow between the experiment and the calculations. When the ball valve of the air line opens at zero second, the air suddenly flows into the apex and the water flow decreases like a step. Both codes predict the transient at this point well. For the RELAP5/MOD3.3 simulation, the oscillation of the flow rate becomes considerable after about 25 seconds. On the other hand, for the SPACE3.0 simulation, the fluctuation of the flow rate increases from about 50 seconds after the siphon is almost blocked.

4. Conclusions

The simulations of siphon break experiments were performed using SPACE3.0 and RELAP5/MOD3.3. In the 14-inch LOCA with a 4-inch siphon breaker, both SPACE3.0 and RELAP5/MOD3.3 calculate the pool level lower than the experiment when the siphon phenomenon is finished, and SPACE3.0 predicts much lower pool level than RELAP5/MOD3.3. Both SPACE3.0 and RELAP5/MOD3.3 well predict the POSTECH experiment with the 14-inch break size and 6-inch siphon breaker and the Idaho state university experiment. From the validation calculation of the siphon break experiments, we confirm that the SPACE code has a prediction performance similar to that of RELAP5 code. It seems necessary to modify the flow pattern map or to develop a component model to predict the siphon blocking phenomena well.

Acknowledgement

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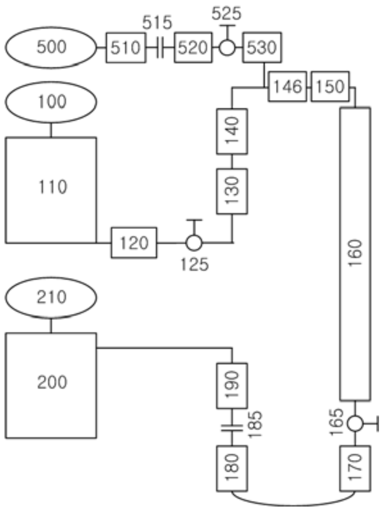

Fig. 4. Modeling of the experimental facility at Idaho State University.

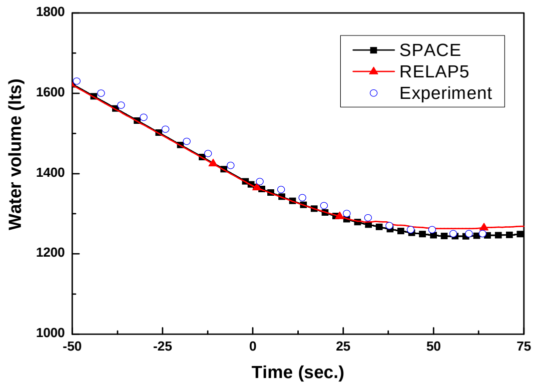

Fig. 5. Prediction of water volume

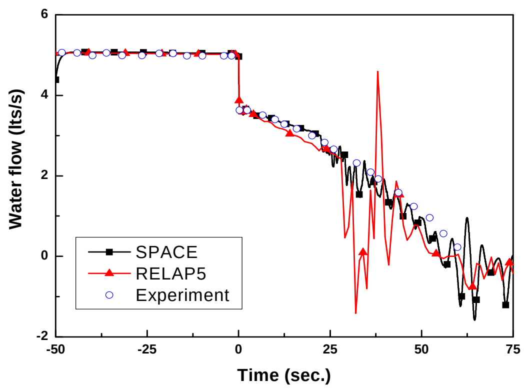

Fig. 6. Prediction of water flow rates