Prediction Model Development for Siphon Break Phenomena in a Research Reactor

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1. Introduction

In a research reactor, the reactor core is cooled by a natural circulation through some opening valves to the reactor pool after the primary cooling pump is turned off. The pool water itself is the ultimate heat sink of the residual heat. Thus, it is very important to guarantee that the pool water level is higher than the minimum level from a nuclear safety point of view. In an open pool-type research reactor, however, a component of the system can be installed below the core level due to the component's purpose. The pool water is then drained below the core by a siphon effect, and the core cannot be cooled by natural circulation when a postulated pipe break occurs below the reactor core position. Therefore, the system should install a siphon breaker to limit the pool water drain during and after all postulated initiating events.

2. Prediction model and Results

A siphon break test was performed at Pohang University of Science and Technology (POSTECH)[1]. A schematic diagram of the test facility is shown in Figure 1.

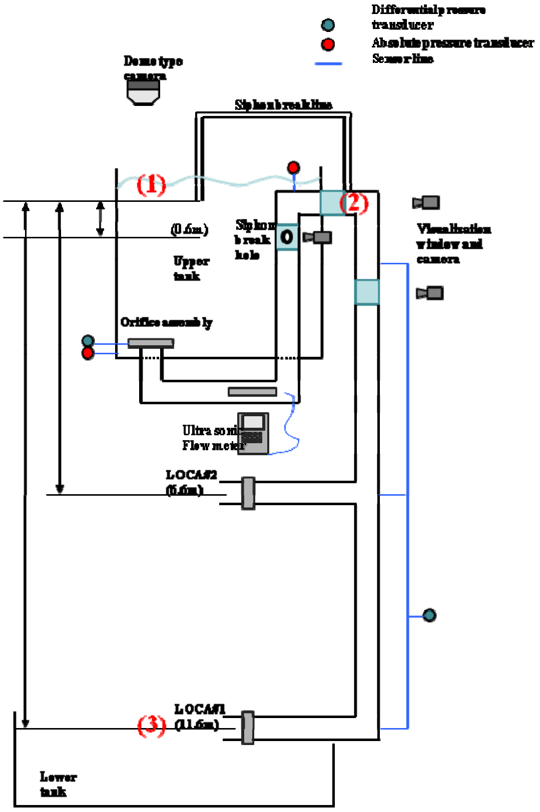

Fig. 1. Schematic diagram of siphon breaker test facility

2.1 Prediction Model Development

As an air volumetric flow rate through a siphon breaker increases, the siphon quickly breaks and the undershooting height decreases. To consider the air flow effect, a resistance coefficient K of the siphon breakers is used.[2] From the definition of K, the air velocity is

$$v = \sqrt{\frac{2\Delta P}{\rho K}} \; . \tag{1}$$

The volumetric flow rate is then calculated as

$$\dot{Q} = Av = A\sqrt{\frac{2}{\rho K}} \cdot \sqrt{\Delta P} = F \cdot \sqrt{\Delta P} \; . \tag{2}$$

Here, F is defined as an air flow rate factor, and ΔP is the differential pressure between the inner side of the 16-inch main pipe near the siphon breakers and the atmosphere.

Next, the inner pressure of the main pipe is dependent on the liquid flow. From the Bernoulli equation [3] among positions *(1)*, *(2)*, and *(3)* in Figure 1, the velocity of position *(3)* and pressure of position *(2)* are

$$v_3 = \sqrt{2g(h_1 - h_3)} = \sqrt{2g \cdot \Delta h} \tag{3}$$

$$P_2 = \frac{1}{2}\rho(1 - \frac{A_3^2}{A_2^2})v_3^2 - \rho g(h_2 - h_3) \; . \tag{4}$$

Because the distance between position *(2)* and *(3)* is constant, the ΔP has the following relationship from equations (3) and (4):

$$\Delta P \sim (1 - \frac{A_3^2}{A_2^2}) \cdot \Delta h \; . \tag{5}$$

Then, from equations (2) and (5), the air flow rate has the following relationship:

$$\therefore \dot{Q} \sim F \cdot \sqrt{(1 - \frac{A_3^2}{A_2^2}) \cdot \Delta h} \; . \tag{6}$$

Therefore, the effects of the hydrostatic head and the pipe break size are reflected in the below equations, respectively:

$$water \bullet air = \frac{\Delta h_b}{\Delta h_a} \bullet \left(\frac{\Delta h_b}{\Delta h_a}\right)^{1/2} = \left(\frac{\Delta h_b}{\Delta h_a}\right)^{3/2} \tag{7}$$

$$water \bullet air = \frac{A_{3,b}}{A_{3,a}} \bullet \left(\frac{A_2^2 - A_{3,b}^2}{A_2^2 - A_{3,a}^2} \right)^{1/2} \quad . \qquad (8)$$

Finally, the form of the analytical model for the undershooting height prediction is

$$y = f(F(a)) \left(\frac{\Delta h_b}{\Delta h_a} \right)^{3/2} \left\{ \frac{A_{3,b}}{A_{3,a}} \bullet \left(\frac{A_2^2 - A_{3,b}^2}{A_2^2 - A_{3,a}^2} \right)^{1/2} \right\} . \qquad (9)$$

2.2 Prediction Results

Figures 2 and 3 show the experimental and prediction results considering the hydrostatic head effect. For f(F(a)), the function of the siphon break hole test results at LOCA #1 is used. This shows that the model predicts the experimental data well. Figures 4 and 5 show the results considering the effect of the pipe break size, and the function of the siphon break line test results in the 10-inch pipe break size is used for f(F(a)). The prediction by the model has some deviation from the experimental data.

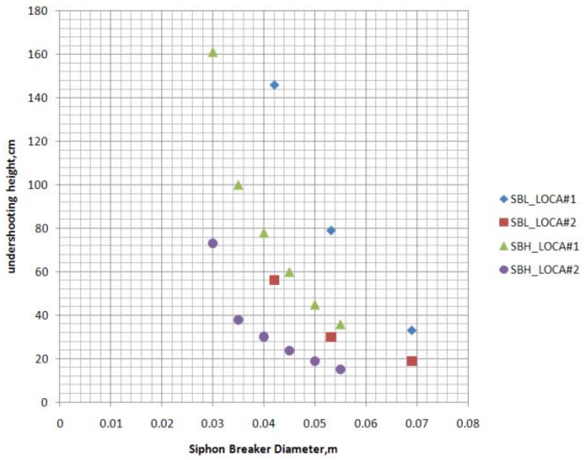

Fig. 2. Experimental results with 10-inch LOCA

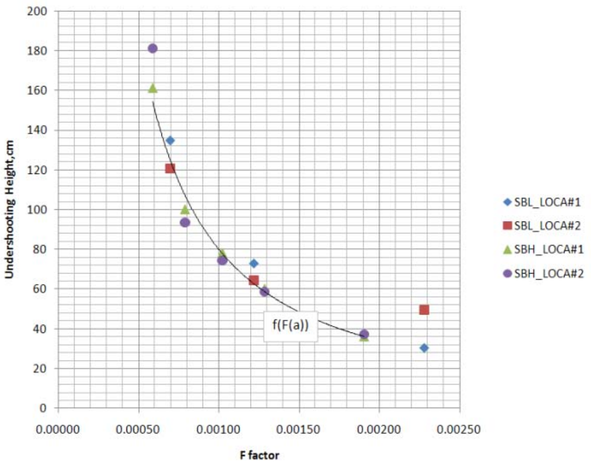

Fig. 3. Model prediction results with 10-inch LOCA

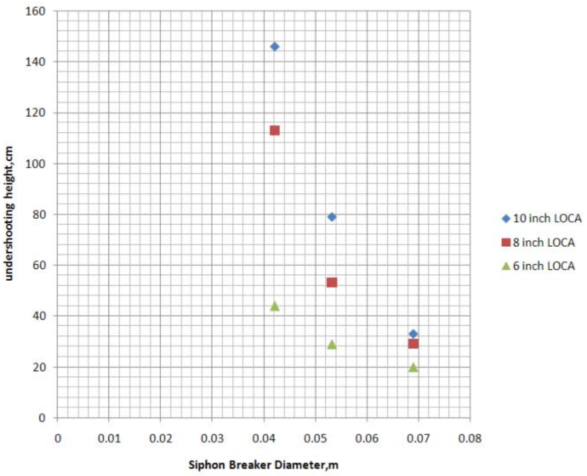

Fig. 4. Experimental results at LOCA#1

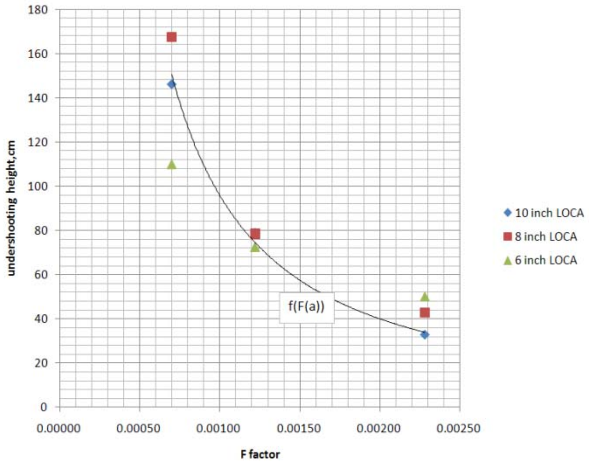

Fig. 5. Model prediction results at LOCA#1

3. Conclusions

An analytical study was carried out to understand siphon break phenomena inside a large pipe of a research reactor. The prediction model is capable of predicting the siphon break phenomena and the undershooting height roughly.

REFERENCES

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[3]Munson, B.R., Young, D.F., and Okiishi T.H., “ Fundamentals of fluid mechanics”, 1990