Preliminary Design of Siphon Breakers in Research Reactors

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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 to meet the required net positive suction head (NPSHr) of the primary cooling pumps. When a postulated pipe break occurs below the reactor core position, the pool water is drained below the core by siphon phenomena, and the core cannot be cooled by a natural circulation. Therefore, siphon breakers should be installed in the system to limit the pool water drain during and after all postulated initiating events.

2. Design of Research Reactors

DOE category III (pool-type) reactors are divided into two broad subgroups based on the maximum steady-state thermal power of the reactor. [1] The power ranges that define the subgroups are

A. Power ≤ 1 MW
B. 1 MW < Power ≤ 10 MW .

The first subgroup does not require active systems for reactor heat removal. Natural circulation is sufficient to cool the core. The second subgroup requires forced circulation to remove high reactor power (> 1MW). Additionally, a third subgroup operating at greater than 10 MW thermal power is considered.

Here, the design of the second and third subgroups is briefly described. The research reactors in the second subgroup require a relatively small coolant flow rate for the forced circulation and have one line from the reactor core which is less than the size of a 16-inch pipe. The main line is divided into two or three pump suction lines. For the third subgroup, two lines from the reactor core are easily considered because of a large coolant flow rate, and the lines are larger than an 18-inch pipe. They are also divided into three of four pump suction lines. Because open-type reactors are operating at low pressure and low temperature conditions, LB LOCA (Large Break Loss Of Coolant Accident) is almost impossible except a nearby pump, which has a moving part. Thus, a pump casing rupture is only considered as LB LOCA in this study.

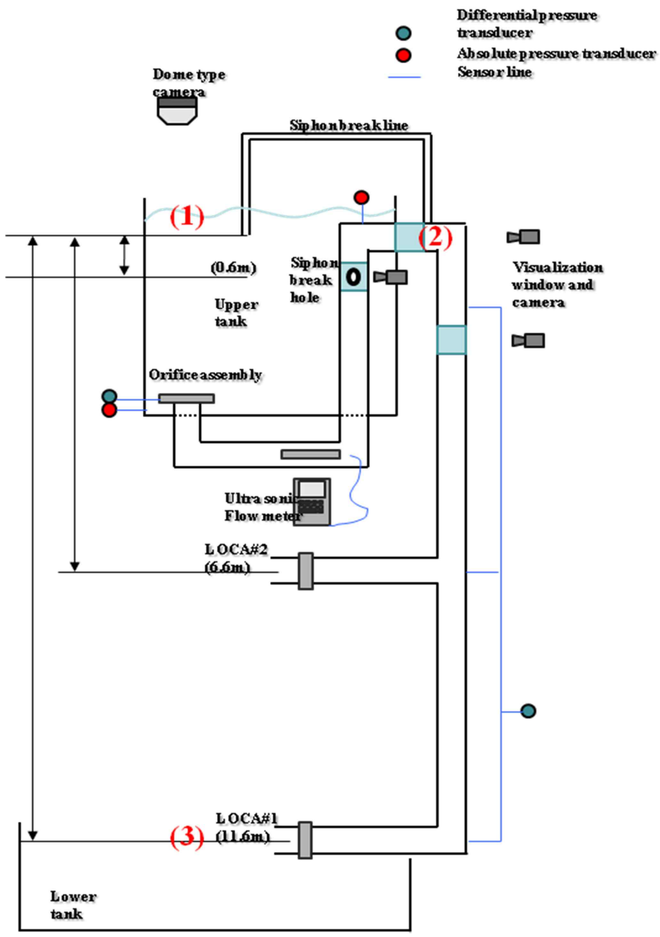

Fig. 1. Schematic diagram of siphon breaker test facility

3. Undershooting height prediction model

An analytical model developed by Lee et al. [2] is used to design siphon breakers for one reactor less than 10 MW and another reactor greater than 10 MW. The air volumetric flow rate effect, water flow effect to the air side, and the effects of a hydrostatic head and pipe break size are considered in this model. The final form of the analytical model for the undershooting height prediction is

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

Here, y is an undershooting height, F is an air flow rate factor defined as $A\sqrt{2/\rho K}$, where A is the area, ρ is the density, and K is the resistance coefficient. Positions (1), (2), and (3) are described in Figure 1. (1) is a pool water surface, (2) is the apex where the siphon break line and main pipe meet, and (3) is the free surface at the LOCA position. Also, *a* is a reference case and *b* is that we want to know the undershooting height. In this study *f(F(a))* is $0.0149F^{-1.243}$, which is a function of the siphon break hole test at LOCA #1 in the test results by POSTECH. [3]

4. Preliminary Design of Siphon Breakers

Siphon break valves are installed on the siphon break lines of the reactor inlet/outlet pipes outside the pool. When the pool water level drops to a limited level, the siphon break valves are opened, and siphon drainage stops automatically. The pool water level is guaranteed well above the top of the reactor structure assembly in any Design Basis Accident. It guarantees the natural convection flow for the decay heat cooling of the core.

4.1 Research reactor less than 10 MW

One 16-inch main pipe and two 10-inch pump suction lines are assumed with an 11 m hydrostatic head, which means the elevation difference between the end of the siphon break line inside the pool and the LOCA position. 2 to 3-inch siphon break lines with globe type siphon break valves are considered as siphon breakers. They have a 10m straight length, four 90° elbows, one entrance, and one exit.

Figure 2 shows the results of a siphon breaker design for a reactor of less than 10MW. The design conditions for the siphon breakers are very similar with the experimental conditions of the reference case. The undershooting height of a 3-inch siphon breaker is calculated by the extrapolation of the prediction model. A 2.5-inch siphon breaker has a 0.46m undershooting height. This is reasonable to guarantee nuclear safety considering a safety factor of 2 because we assume that 1.0m is a design margin of the undershooting height.

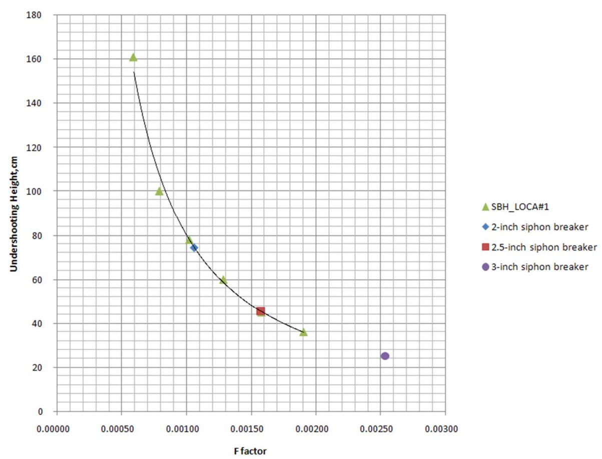

Fig. 2. Experimental results with 10-inch LOCA

4.2 Research reactor greater than 10 MW

Two 18-inch main pipes and three 16-inch pump suction lines are assumed with an 11 m hydrostatic head. 3.5 to 5-inch siphon break lines with globe type siphon break valves are considered as siphon breakers for each main pipe. They have a 10 m straight length, four 90° elbows, one entrance, and one exit.

Figure 3 shows the prediction results by the extrapolation of the prediction model. Because the design conditions are different with the reference case, the undershooting height decreasing slope according to the air flow rate factors is different with that of the reference case. Here, a 4-inch siphon breaker is sufficient to guarantee nuclear safety with a 0.47m undershooting height.

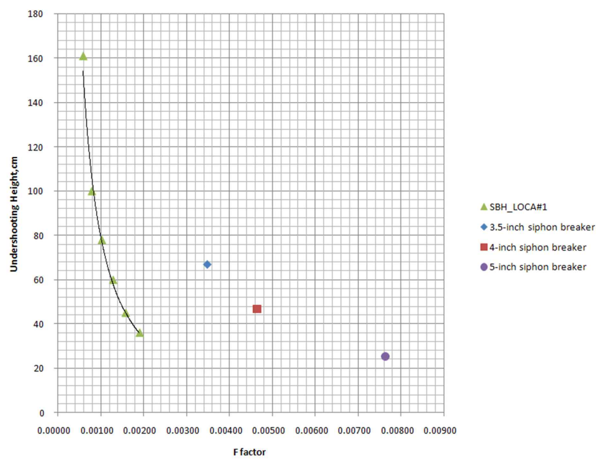

Fig. 3. Model prediction results with 10-inch LOCA

5. Conclusions

A preliminary design for siphon breakers was performed considering the thermal power of the reactor. 2.5-inch and 4-inch siphon breakers were recommended for research reactors of less than 10MW and greater than 10MW, respectively. These results are very conservative because the model does not consider the resistance coefficient of the liquid flow in the main pipe. If this model is upgraded as an elaborated model considering the resistances of the pipe and the equipment for the liquid flow side, the predicted undershooting height will be reduced, and smaller size siphon breakers can be selected.

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