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Experimental study of small scale siphon breaker to verify Siphon Breaker Simulation Program (SBSP)

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ABSTRACT

This study was conducted with the design of a small scale siphon breaker using the Siphon Breaker Simulation Program (SBSP). The feasibility of SBSP was researched in a small scale experimental facility. C factor, Chisholm B coefficient, and simulation results of the Undershooting Height (UH) were obtained by the SBSP. The major parts of the experimental facility are an upper tank, a lower tank, a downcomer, and a Siphon Breaker Line (SBL). The experiment variables are LOCA sizes of 30 and 38 mm and SBL sizes of 2/8, 3/8, and 4/8 in. The overall analysis of the air sweep-out mode was conducted by observing the differential pressure, flow patterns in the downcomer, and the UH. In addition, the reasons for the deviation of the UH prediction were analyzed in terms of the C factor-Chisholm B coefficient relation. We observed partial and zero sweep-out modes from the experimental results with SBL 3/8 and 4/8 in. In these experiments, the UH prediction results by the SBSP showed an average error of approximately 16 mm, which deviates by 2.5% compared with the height of the upper tank. Therefore, the SBSP predicts the experimental results well. Contrarily, full, partial and zero sweep-out modes were observed for the SBL 2/8 in. experiment. The UH for this experiment was predicted with a maximum error of approximately 48%. Consequently, the experimental results fairly agree with the SBSP model predictions for C factor range of 100,000–420,000. However, the disagreement becomes larger as the C factor increases and since the UH is too big in a high C factor range, in which full sweep-out mode occurs, the high C factor range (over 420,000) should be avoided during the siphon breaker designing stage. Finally, the SBSP could be considered as a reasonable simulation software for designing various scale siphon breakers.

1. Introduction

Recently, the design of a research reactor using a plate-type nuclear fuel, such as the Jordan Research and Training Reactor (JRTR), is gaining popularity. In order to facilitate the fastening method of a plate-type nuclear fuel, the research reactors are designed with a core downward flow. As the research reactor needs to be designed in consideration of the available Net Positive Suction Head (NPSHa) of the primary cooling pump, some equipment such as pumps must be located at a lower level than the reactor core. The coolant in the reactor pool is responsible for the ultimate heat sink of the nuclear fuels in case of an accident and assumes the most important role in the nuclear safety of the research reactor. If the coolant leaks by a pipe rupture, the fuels will not be able to remove the residual heat, increasing the risk of a severe accident. In order to prevent the Loss of Coolant Accidents (LOCA) caused by a siphon phenomenon, a siphon breaker could take an effective role to prevent the siphon phenomenon (McDonald and Marten, 1959).

When the water level in the reactor pool is lower than the position of the end of the Siphon Breaker Line (SBL), due to a negative pressure that is formed in the apex of the main pipe based on the Bernoulli equation, air flowing into the main pipe through the SBL from the atmosphere generates two-phase flow. When the water level becomes lower, the flow rate of water decreases and the siphon breaking phenomenon, which air blocks the flow of water, occurs. As a result, the siphon breaker can prevent severe accidents caused by LOCA.

Several studies have been carried out to increase the safety of the research reactors by blocking the siphon phenomenon. Neill and Stephen (1993) designed an experimental facility with a height of 16 m and a main pipe diameter of 4 in.. The facility installed various orifices at the drain part of the lower tank and the SBL to control the pressure and flow rate. The study confirmed the air sweep-out modes and classified them into zero, partial, and

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Nomenclature

A	Area [m^2]
K	Pressure loss coefficient
Q	Volumetric flow rate [m^3/s]
V	Velocity [m/s]
Z	Height [m]

Mathematical symbols

ρ	Density [kg/m^3]
Φ^2	Two-phase multiplier

Subscript

a	Air
SBL	Siphon breaker line
w	Water
0	Position #0 [refer Fig. 1]
1	Position #1
2	Position #2

full sweep-out modes according to the flow pattern (Neil and Stephens, 1993). Sakurai (1999) proposed an analytical model, which applied a fully separate air-water flow model in order to estimate the results of siphon breaking. Although the model could predict the experimental results, the experiments were conducted only twice and the scale of the experimental facility was too small compared with real research reactors (Sakurai, 1999). For this reason, Kang et al. (2013) designed an experimental facility with a 16 m height and 16 in. diameter of the main pipe, considering the scale of the real research reactor. The study was conducted to demonstrate the siphon breaking phenomenon according to changing LOCA and SBL sizes. In addition, they reported that as the diameter of the SBL size is larger and the LOCA size is smaller, the lower Undershooting Height (UH) results are obtained (Kang et al., 2013). In another paper of Kang et al. (2014), they conducted experiments about the positions of the SBL. As a result, they reported that the final water levels, according to the positions of the SBL, were the same (Kang et al., 2014). Seo et al. (2012) analyzed the experimental results of the reference (Kang et al., 2013) by a CFD method and proposed an analytical model based on the prediction results (Seo et al., 2012). Lee and Kim (2016, 2017a,b) analyzed the siphon breaking phenomenon theoretically and developed the Siphon Breaker Simulation Program (SBSP) using the Chisholm model, which analyzed two-phase phenomena theoretically in order to assist the phenomenological analysis (Lee and Kim, 2016, 2017a,b). Furthermore, the SBSP was verified with the experimental data of Kang et al. (2011).

SBSP was developed using real (large) scale experimental data. The purpose of this research is to verify whether the SBSP can also be applied on small scales of siphon breaker design. By doing this research, we want to verify the performance of the SBSP for various scales of siphon breaker. Using the SBSP, we designed and manufactured a small scale siphon breaker experimental facility by reducing it to 1/8 scale of the real research reactor size, and experimented with SBL and LOCA sizes. Experimental results were compared with the prediction results of the SBSP. We confirmed the performance of the designed siphon breaker and verified whether the SBSP is appropriate for use in various scale siphon breaker designs of research reactors.

2. System description

2.1. Simulation and design

Fig. 1 is a schematic diagram of the experimental facility and the numbers of Fig. 1 signify the position. Position #0 is the position of the SBL's end, position #1 is the water level in the upper tank, position #2 is the part where the SBL and the main pipe are connected, and position #3 is the LOCA position. There are two tanks, the upper and the lower tank. The water in the upper tank is drained by the siphon effect and accumulated in the lower tank at the bottom. In addition, the flow patterns are observed by the visualization pipe with the camera, displayed in blue in Fig. 1.

The SBSP was developed for the prediction of the performance of the siphon breaker according to the design conditions of the research reactor based on the experimental data of Kang et al. (2011). Therefore, in order to investigate the validity of the SBSP at various scales, an experimental facility was designed within the design range of the SBSP with a C factor-Chisholm B coefficient. In addition, the experimental results in the range beyond the C factor-Chisholm B coefficient of Kang et al. (2011) need to be evaluated in order to check whether the SBSP can accurately predict the results.

$$\Phi^2 \equiv 1 + \left(\frac{\rho_w}{\rho_a} - 1\right)(B \times X(1 - X) + X^2) \quad (1)$$

$$X \equiv \frac{\rho_a V_{02} A_0}{\rho_w V_{12} A_2 + \rho_a V_{02} A_0} \quad (2)$$

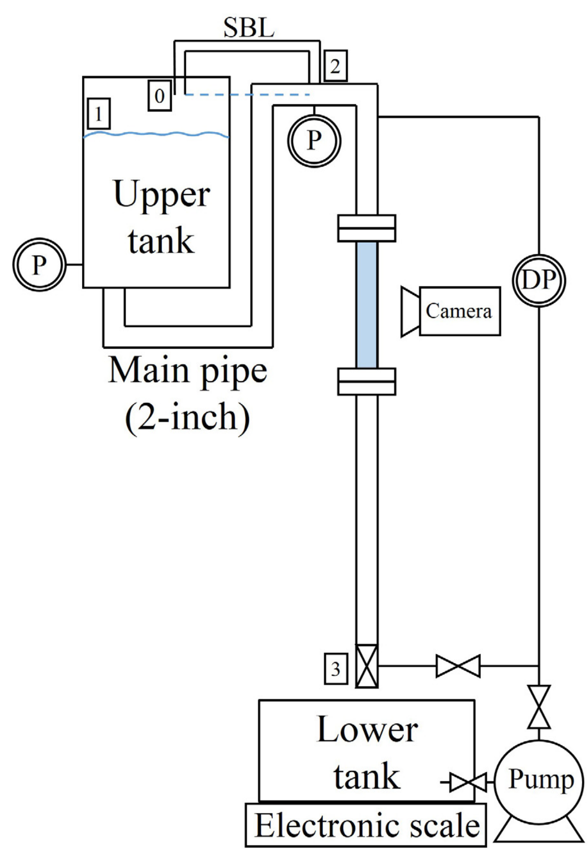

Fig. 1. Schematic diagram of the experimental facility.