Annals of Nuclear Energy 101 (2017) 49–57

Contents lists available at ScienceDirect

Annals of Nuclear Energy

journal homepage: www.elsevier.com/locate/anucene

Development of siphon breaker simulation program for investing loss of coolant accident of a research reactor

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ARTICLE INFO

Article history:
Received 18 May 2016
Received in revised form 31 August 2016
Accepted 25 September 2016

Keywords:
Loss of coolant accident
Research reactor
Siphon
Siphon breaker
Siphon breaker simulation program

ABSTRACT

Under the design conditions of a research reactor, the siphon phenomenon induced by pipe rupture can cause continuous efflux of water. In order to prevent water efflux, an additional facility is necessary. A siphon breaker is a type of safety facility that can resist the loss of coolant effectively. However, analysis of siphon breaking is complex since it comprises two-phase flow and there are many inputs to be considered. For this reason, in order to facilitate the analysis and design of the siphon breaker, a simulation program based on fluid mechanics was developed using MFC (Microsoft Foundation Class) programming. From Bernoulli's equation, the velocity and quantity as well as undershooting height, water level, pressure, friction coefficient, and factors related to the two-phase flow could be calculated. The Chisholm model, which was included in the program to analyze the two-phase flow, can predict the results in a manner similar to those obtained from a real-scale experiment. By modifying the values of the input parameters and analyzing the results with respect to loss of coolant accident (LOCA) locations, the size of pipe and coefficients could be compared easily. Since simulation results are shown in the form of a graph, the user is able to confirm the total breaking situation. Furthermore, it is possible to save the entire simulation results. The simulation results were shown to be similar to those obtained from the real-scale experiment and the program functioned correctly. By using the program, the user is easily able to confirm the status of the siphon breaking, and the program is also helpful in the design of the siphon breaker.

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1. Introduction

The number of reactors using plate-type fuel, such as the JRTR (Jordan Research and Training Reactor), has increased recently. In order to connect the plate-type fuel easily, the research reactor requires core downward flow. Since it needs to meet the condition of net positive suction head in the primary cooling system, some facility should be positioned below the reactor. 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 to the air. This means that the residual heat cannot be removed, which could lead to a serious accident. Therefore, when a loss of coolant accident (LOCA) occurs, a safety facility is necessary to prevent a serious accident. A siphon breaker is a type of safety facility which can prevent water efflux effectively by using an inrush of air.

Several studies for the improvement of research reactor safety have been conducted. McDonald and Marten (1958) carried out an experiment in order to confirm the performance of siphon breaking valve as an actively operation type. The purpose of their experiment was to block the reverse flow of sodium on a sodium graphite reactor. Neill and Stephens (1993) performed an experiment using a siphon breaker as a passively operated device in a small-sized pipe. They used various size of orifices to control the flow rate of water and air. In order to explain their experiment results, they developed the concept of air sweep-out mode; zero sweep-out mode, partial sweep-out mode, and fully sweep-out mode. Sakurai (1999) proposed an analytical model to analyze the siphon breaking whereby a fully separate air-water flow model was applied. Their model could show the reasonable results with experimental data. However, only two experiments were conducted and the scale of the experimental facility is too small in comparison with actual research reactor. In Korea, real-scale verification experiments were performed by using a large-sized pipe (Kang et al., 2011, 2013). Various LOCA and SBL size, siphon breaker type, and the presence of orifice regarding reactor fuel were considered. Through the experiment, the evaluation could

Abbreviations: LOCA, loss of coolant accident; SBL, siphon breaker line.

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http://dx.doi.org/10.1016/j.anucene.2016.09.041
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Nomenclature

A	Area [m^2]
B	Chisholm coefficient
D	Inner diameter [m]
f	Friction factor
g	Gravitational acceleration [m/s^2]
K	Pressure loss coefficient
L	Length [m]
P	Pressure [kPa]
Q	Volumetric flow rate [m^3/s]
V	Velocity [m/s]
X	Quality
Z	Height [m]

Mathematical symbols

α	Void fraction
ρ	Density [kg/m^3]
ϕ^2	Two-phase multiplier
μ	Viscosity coefficient [Ns/m^2]

Subscript

a	Air
w	Water
m	Mixture
SBL	Siphon breaker line
atm	Atmosphere

be conducted about the elements that affect the siphon breaking. The significant point of this experiment is that the experiment results can be applied to the actual siphon breaker design in research reactor, because the experiment was performed with real-scale. In addition, Seo et al. (2012) proposed an analytical model for the experimental results by using CFD (Computational Fluid Dynamics).

The calculation of siphon breaking is excessively complex because there are many parameters need to be considered. Therefore, previous studies have not presented a satisfactory theoretical model for siphon breaking. For this reason, a program was developed which can easily simulate siphon breaking. In order to develop the simulation program, theoretical analysis processes were performed using fluid dynamics and an algorithm implementation process. Furthermore, in order to design a user-friendly interface, the simulation program was developed using a GUI (Graphic User Interface) program. Finally, the simulation program includes formulae for analyzing the siphon breaking and the program can show the results in various ways.

2. Development of program

Fig. 1 shows a schematic diagram of the siphon breaker. In the figure, the numbers indicate relevant positions: position 0 signifies the entrance of the siphon breaker; position 1 signifies the water level; position 2 signifies the connected part of the siphon breaker and the main pipe; and position 3 signifies the LOCA position.

After water efflux occurs, water leaks out until the water level reaches position 0. As soon as the water level drops below position 0, air rushes into the siphon breaker. In other words, two-phase flow in the main pipe proceeds at this time and it continues until the air stops the water efflux completely.

The siphon breaking system performs differently according to conditions; that is, input parameters set by the user. The list of input parameters is shown in Table 1, and the default values of input parameters are provided in Kang et al. (2013), with a LOCA size of 16 in., and a siphon breaker line (SBL) size of 2.5 in. The values of pressure loss coefficient K_{12} and K_{23} were calculated by considering the siphon breaker design and CRANE Co. (1988). Because the Chisholm coefficient B, which is included in the two-phase flow analysis model, depends on mass flow, it needs to be entered by the user.

2.1. Analytical process by fluid dynamics

The program is able to calculate the siphon breaking using the input parameters. The number of results is 15, and the output parameters consist of the following parameters: velocity of fluid,

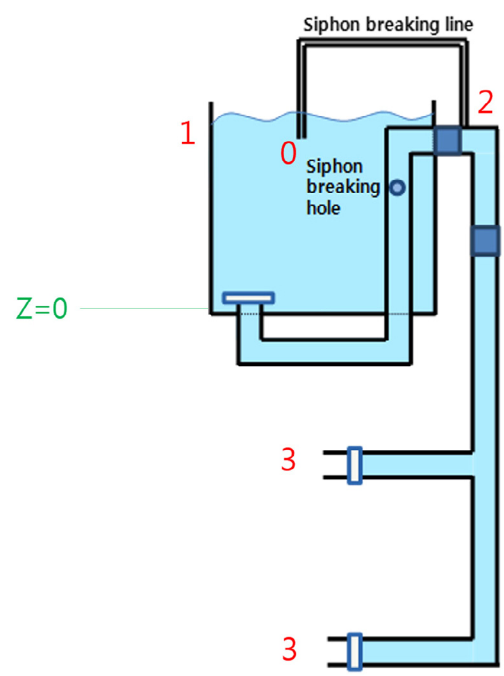

Fig. 1. Schematic diagram.

quantity of fluid, water level, undershooting height, pressure, quality, void fraction, mixture density, two-phase multiplier, pressure loss coefficient K_{02}, friction factor, and the Reynolds number. These output parameters are derived from the formulae included in the program. The alphabetical and Greek symbols represent physical conditions used in the formulae. For example, P represents pressure; V represents velocity; Q represents volumetric flow rate; K represents pressure loss coefficient; Z represents height; g represents gravity; ρ represents density; ϕ^2 represents the two-phase multiplier; μ represents viscosity; A represents area; f represents friction factor; L represents length; and D represents diameter. In the following formulas, numerical subscripts signify each position. For example, P_1 represents the pressure at position 1. Some symbols have two numerical subscripts. In this cases, the subscripts mean a section which is between first numerical number and second numerical number. For example, V_{12} represents the velocity between position 1 and position 2. Likewise, V_{02} represents the velocity between position 0 and position 2 and V_{23} represents the velocity between position 2 and position 3. Similarly, other symbols, Q_{02}, Q_{12}, Q_{23}, K_{02}, K_{12}, and K_{23}, mean the values of the section of the subscript.

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