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Performance Verification for Safety Injection Tank with Fluidic Device

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1. Introduction

Safety Injection Tanks (SITs) provide a means of rapid reflooding of the core following a Large Break Lose of Coolant Accident (LBLOCA), and keeping it covered until the safety injection pumps becomes available. In LBLOCA, the SITs of a conventional nuclear power plant deliver excessive cooling water to the reactor vessel causing the water to flow into the containment atmosphere. In an effort to make it more efficient, Fluidic Device (FD) is installed inside a SIT of Advanced Power Reactor 1400 (APR 1400).

FD, a complete passive controller which doesn't require actuating power, controls injection flow rates which are susceptible to a change in the flow resistance inside a vortex chamber of FD. When SIT Emergency Core Cooling (ECC) water level is above the top of the stand pipe, the water enters the vortex chamber through both the top of the stand pipe and the control ports resulting in injection of the water at a large flow rate. When the water level drops below the top of the stand pipe, the water only enters the vortex chamber through the control ports resulting in vortex formation in the vortex chamber and a relatively small flow injection [1, 2].

Performance verification of SIT shall be carried out because SITs play an integral role to mitigate accidents. In this paper, the performance verification method of SIT with FD is presented.

2. Performance Verification for SIT

Expansion of nitrogen is accompanied by a decrease of nitrogen temperature during a blow-down. Heat transfer can occur from outside to SIT because the nitrogen temperature of SIT becomes lower than that of outside. However, conventional SITs neglect the effect of heat transfer because it takes about 40 seconds to inject all ECC water into Reactor Coolant System (RCS). In contrast, the SIT of APR 1400 has to consider the heat transfer because it takes about 200 seconds to inject all ECC water into RCS. The time means the nitrogen temperature increases due to the heat transfer from outside after turndown which means the injection flow rate changes from a high flow rate to a low flow rate. Therefore, the performance verification method of conventional SIT is not applied for APR 1400. Thus, a new methodology for the performance verification of SIT is required, and that is directly calculating the flow resistance coefficient (K) for SIT.

In the present study, the Bernoulli's equation considering flow resistance for pipe is used to calculate the flow resistance coefficient (K). The equation is expressed as:

$$\frac{P_1}{\rho g}+z_1+\frac{V_1^2}{2g}=\frac{P_2}{\rho g}+z_2+\frac{V_2^2}{2g}+K\frac{\bar{V}^2}{2g} \tag{1}$$

In the above equation, ρ is the density of fluid and g is the acceleration of gravity. Eq. (1) is rearranged for the flow resistance coefficient (K) as shown below:

$$K=\frac{2g}{\bar{V}^2}\left(\frac{P_1-P_2}{\rho g}+\frac{V_1^2-V_2^2}{2g}+z_1-z_2\right) \tag{2}$$

A schematic diagram of SIT performance verification is shown in Fig. 1. D_1 is the inner diameter of SIT, Z is the total height of the water level instrument between lower and upper taps, h is the vertical distance from the lower tap of water instrument to reactor vessel, D_2 is the inner diameter of the discharge pipe, A_1 is the cross-sectional area of SIT, A_2 is the cross-sectional area of the discharge pipe, V_1 is fluid velocity in SIT, V_2 is fluid velocity in discharge pipe, H represents the SIT water level, and the reactor vessel is at atmospheric pressure. The SIT filled with ECC water is pressurized with nitrogen. A gate valve is installed in the discharge pipe to prevent the water from injecting into the reactor vessel. The valve takes 30 seconds to fully open. A differential pressure transmitter is used to measure the water level in SIT. The water level is represented by the percentage. Pressure instrument is also installed on the upper part of SIT to measure nitrogen pressure in the SIT. The interval time of data acquisition from each instrument is 0.05 second. When the level instrument indicates 45%, the turndown occurs. As the inner diameter of SIT is much bigger than that of the discharge pipe (D_1 >> D_2), the fluid velocity in the discharge pipe is much greater than that in the tank (V_2>> V_1). Therefore, the equation (2) is arranged as below:

$$K=\frac{2g}{V_2^2}\left(\frac{P_1}{\rho g}-\frac{V_2^2}{2g}+H+h\right) \tag{3}$$

The fluid velocity (V_2) is deduced from the decreasing rate of SIT water level as follows:

$$V_2=\frac{\Delta H A_1}{A_2\Delta t}=\frac{A_1}{A_2}\frac{H(t)-H(t+\Delta t)}{\Delta t} \tag{4}$$

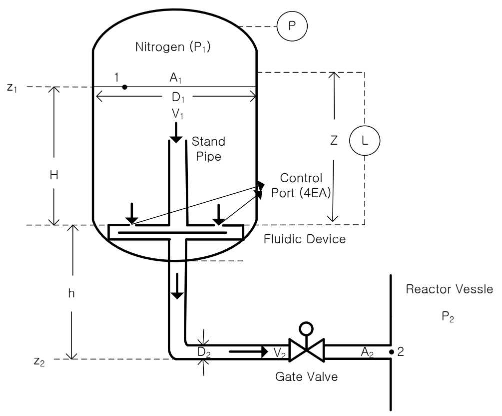

Fig. 1 Schematic Diagram of SIT Performance Verification

The flow resistance coefficient (*K*) for pipe flow is generally determined using Eq. (3). However, the fluid velocity (V_2) which is calculated by Eq. (4) has physically impossible negative velocity values or some abnormal spikes appearing due to uncertainty of the water level instrument. To get rid of such values, an outlier elimination process shall be performed. However, it takes too much time to carry out an outlier elimination process for on-site SIT performance verification. Therefore, a simple method which reduces the effect of uncertainty and can be done on-site is required. Thus, the first and last values for the SIT water level and the arithmetic mean of the first and last values for the pressure instrument are used to calculate the flow resistance coefficient (*K*). The calculation area for a high flow region is set to be from 30 seconds after the gate valve open to the water level of 46% and for a low flow region, it is set to be from 20 seconds after the turndown to the water level of 10% to minimize the flow resistance of gate valves and the uncertainty of water level instrument. The calculation areas of test data are summarized in Table I. The fluid velocity in the discharge pipe (V_2), SIT nitrogen pressure (P_1), and SIT water level (*H*) for high flow region are defined as:

$$V_2 = \frac{\Delta H A_1}{\Delta t A_2} = \frac{A_1}{A_2}\frac{0.01Z\left(H^1 - H^2\right)}{t^2 - t^1}$$

$$P_1 = \frac{P_1^1 + P_1^2}{2}$$

$$H = \frac{0.01Z\left(H^1 + H^2\right)}{2}$$

Therefore, Eq. (3) is expressed as below:

$$K = 2g\left(\frac{A_2\left(t^2 - t^1\right)}{0.01Z A_1\left(H^1 - H^2\right)}\right)^2 \left\{\frac{\left(P_1^1 + P_1^2\right)}{2\rho g} - \frac{1}{2g}\left(\frac{0.01Z A_1\left(H^1 - H^2\right)}{A_2\left(t^2 - t^1\right)}\right)^2 + \frac{0.01Z\left(H^1 + H^2\right)}{2} + h\right\} \quad (5)$$

$$K = 2g\left(\frac{A_2\left(t^4 - t^3\right)}{0.01Z A_1\left(H^3 - H^4\right)}\right)^2 \left\{\frac{\left(P_1^3 + P_1^4\right)}{2\rho g} - \frac{1}{2g}\left(\frac{0.01Z A_1\left(H^3 - H^4\right)}{A_2\left(t^4 - t^3\right)}\right)^2 + \frac{0.01Z\left(H^3 + H^4\right)}{2} + h\right\} \quad (6)$$

The Eq. (5) and (6) are respectively used for calculating flow resistance coefficients (*K*) for high and low flow regions.

Table I: Calculation Area of Test Data

High Flow Region	Water Level (%)	H^1	Water level at 30s after the gate valve opens.
		H^2	Water level of 46%
	Pressure (kg/cm^{2}A)	P^1	Pressure at 30s after the gate valve opens.
		P^2	Pressure at water level of 46%
	Time (sec.)	t^1	30s after the gate valve opens
		t^2	Time at water level of 46%
Low Flow Region	Water Level (%)	H^3	Water level at 20s after turndown
		H^4	Water level of 10%
	Pressure (kg/cm^{2}A)	P^3	Pressure at 20s after turndown
		P^4	Pressure at water level of 10%
	Time (sec.)	t^3	20s after turndown
		t^4	Time at water level 10%

3. Validation

Table II shows comparison of the flow resistance coefficients (*K*) for one SIT obtained from Eq. (5) and (6) with those obtained from Eq. (3) using outlier elimination. The difference of the flow resistance coefficients (*K*) between the results is 4.15% in the high flow region and 3.32% in the low flow region, which shows good agreement between them. Therefore, the proposed method in this paper using Eq. (5) and (6) is reasonable to calculate the flow resistance coefficient (*K*) for SIT.

Table II: Comparison of flow resistance coefficient (*K*)

Calculation method	Flow resistance coefficient (*K*)	
	High flow region	Low flow region
Eq. (5) and (6)	18.08	92.80
Eq. (3) using outlier elimination	17.36	89.82
Difference (%)	4.15	3.32

4. Conclusions

In this paper, the equations for calculation of flow resistance coefficient (K) are induced to evaluate on-site performance of APR 1400 SIT with FD. Then, the equations are applied to the performance verification of SIT with FD and good results are obtained. The proposed method in this paper will be applicable to other nuclear power plants' performance verification of SIT with FD as well.

REFERENCES

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