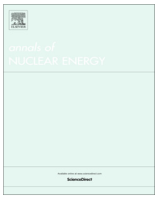
Annals of Nuclear Energy 112 (2018) 143–149

Contents lists available at ScienceDirect

Annals of Nuclear Energy

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



Prediction of performance of Safety Injection Tank with Fluidic Device using a model of two flow paths and its effect on LBLOCA

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ARTICLE INFO

Article history:
Received 8 May 2017
Received in revised form 25 September 2017
Accepted 26 September 2017

Keywords:
Safety Injection Tank
Fluidic Device
Two flow path model
Hydraulic resistance
Nitrogen gas effect

ABSTRACT

To predict the performance of the Safety Injection Tank (SIT) with Fluidic Device (FD) of APR1400 (Advance Power Reactor 1400) and its effect on Large Break Loss-of-Coolant Accident (LBLOCA) of APR1400, a model using two flow paths within the SIT is developed such that a flow path along the standpipe and a flow path through the connecting holes to mixing chamber of the FD can be simulated. A method to determine the hydraulic resistance of each flow path based on the hydrodynamic consideration is also developed. Since the method requires overall K-factor during high SIT flow phase and one during low SIT flow phase, the similarity of the hydrodynamics along the initial SIT pressure is evaluated assuming a simple isentropic process. The transition in those hydraulic resistances from the high flow phase to low flow phase are also considered in terms of K-factor of each flow path. From the course of estimating the overall K-factors, the modeling uncertainties are estimated. A good agreement with the test data and validity of the estimated uncertainty range are found from the calculation of the actual test using MARS-KS code and the present modeling. A LBLOCA of APR1400 plant is calculated using the present modeling scheme and the uncertainties of hydraulic resistance. Effect of nitrogen on cladding thermal response is discussed.

1. Introduction

Safety Injection Tank (SIT) of nuclear power plants is one of the important safety features to provide a large amount of cooling water passively to the reactor vessel following a Loss-of-Coolant Accident (LOCA). However, significant portion of the injected water from SIT is bypassed the reactor vessel to the break, i.e. ECC Bypass (Emergency Core Cooling Bypass), due to complex two phase condition established in the reactor vessel downcomer. Accordingly, several design concepts have been proposed for the SIT to reduce the amount of ECC Bypass and to increase the duration of SIT injection in effective manner (Shiraishi et al., 1994; Schulz, 2006). One of the special design is a Fluidic Device (FD) within the SIT vessel. The idea of this design was to provide a longer passive safety injection than the one of the existing accumulator in order to improve a safety performance for Large Break LOCA (Chu et al., 2008). The design has a FD and a standpipe, which establish two flow paths having different hydraulic resistances. The FD has a mixing chamber to combine the flow through the standpipe and the one from the connecting holes, in which the hydraulic head and the flow rate of each flow path are balanced with mutual interaction. As a result, high flow injection phase and the subsequent low flow phase can be achieved as longer than the existing accumulator.

To confirm the performance of the SIT/FD during LBLOCA (Large Break LOCA), a modeling scheme to represent those hydrodynamic process is required as appropriate to system thermal-hydraulic codes such as RELAP5 (RELAP5 Code Development Team, 1995). From the paper of Annals of Nuclear Energy published in 2015, the authors have discussed several modeling schemes to simulate the performance of SIT/FD using the MARS-KS code (KINS, 2016) and concluded the best result could be obtained by the scheme representing two flow paths individually (Bang et al., 2015). The reason was that potential of nitrogen release through the standpipe from the SIT during transition phase from high flow to low flow can be considered using the scheme. The key issue of the modeling scheme of two flow paths was how to determine the hydraulic resistance of each flow path. In that paper, K-factors were determined by the phenomenological consideration based on the VAPER experiment (Chu et al., 2008) and the SIT blowdown test data (KHNP, 2012) conducted at Shinkori Unit 3. However, specific method was not discussed in detail. The present paper is to describe the method to determine those hydraulic resistances (K-factors) with a hydrodynamic background.

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https://doi.org/10.1016/j.anucene.2017.09.047
0306-4549/

And the plant test data used in that paper was one conducted with the initial SIT pressure of 14 bar, which was different from the actual SIT pressure, 44 bar. Therefore, it may be concerned that the K-factors based on 14 bar test data can be applied to the actual LOCA situation of 44 bar. For this concern, it should be evaluated whether the hydrodynamic phenomena of SIT has a similarity along the initial pressure. In the present paper, hydrodynamic similarity on initial SIT pressure is explored. Also the modeling scheme is validated with the plant test data conducted at 44 bar and the amount of nitrogen release and its timing are predicted. In the course of the determination of K-factors, the modeling uncertainty is considered. Finally, the effect of uncertainty of the present SIT/FD modeling scheme is discussed through the calculation of LBLOCA.

2. Modeling scheme

2.1. Similarity on initial pressure

Fig. 1 shows the configuration of SIT and its modeling schemes. Consider a state of SIT discharging to atmosphere of pressure, P_E, in Fig. 1(b), and a continuity equation and Bernoulli equation in a lumped manner as follows

$$\rho A_{tank}(dL/dt) = -\dot{m}_B = -\rho A_B v_B. \tag{1}$$

$$P_A/\rho g + z_A + (v_A^2)/2g = P_B/\rho g + z_B + (v_B^2)/2g + K(v_B^2/2g). \tag{2}$$

where, K is an overall hydraulic loss factor over the system. Defining total loss factor, pressure difference, and maximum flow rate as follows:

$$\pi = K - (A_B/A_{Tank})^2. \tag{3}$$

$$\Delta P = P - P_B. \tag{4}$$

$$\dot{m}_0 = A_B\{2\rho(P_0 + \rho g L_0)/(1+\pi)\}^{1/2}. \tag{5}$$

The continuity equation leads to:

$$\rho A_{tank}(dL/dt) = -\dot{m}_0\{(P + \rho g L)/(P_0 + \rho g L_0)\}^{1/2}. \tag{6}$$

Non-dimensional expressions regarding water level, mass flow rate, gas volume, pressure, and time are introduced as in Eq. (7) (Reyes, 2010). And two additional non-dimensional parameters on initial water head to pressure head and initial gas level to water level as follows:

$$L^+ = L/L_0, \quad m^+ = m/m_0, \quad V_g^+ = V_g/V_{g0}, \quad P^+ = P/P_0,$$
$$P_B^+ = P_B/P_0, \quad t^+ = \tau/t, \quad \tau = \rho V_{g0}/\dot{m}_0. \tag{7}$$

$$N_p = \rho g L_0/P_0, \quad \varphi = L_{g0}/L_0. \tag{8}$$

And assume an isentropic process of the gas expansion as follows

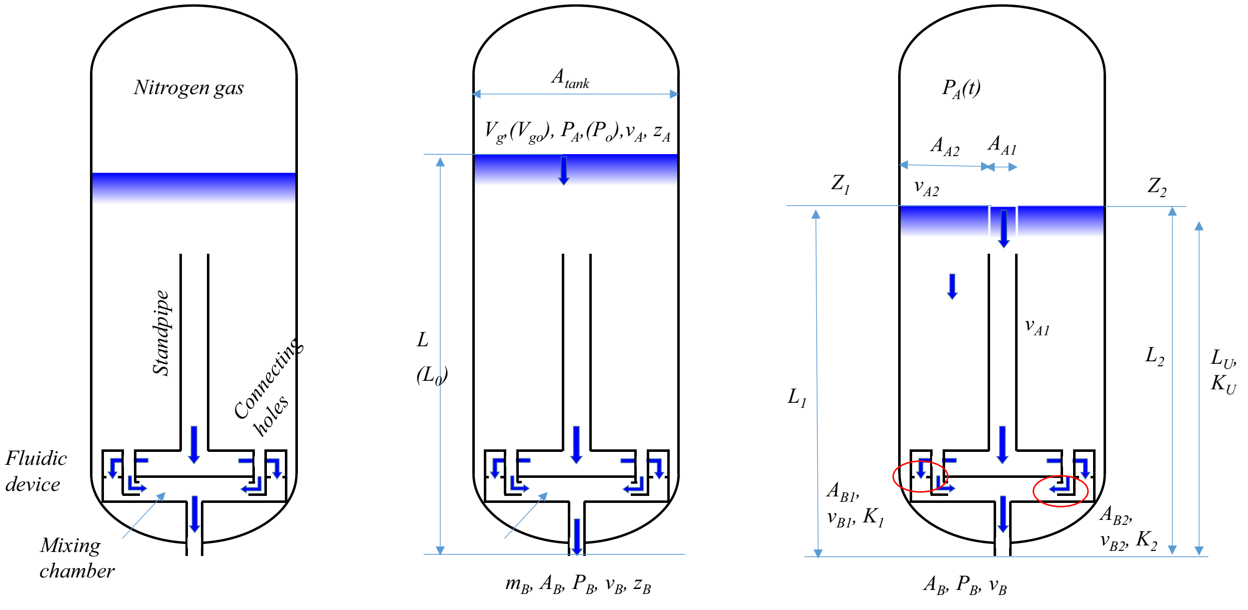
$$P^+ = P/P_0 = (V_{g0}/V_g)^\gamma = (V_g^+)^{-\gamma}. \tag{9}$$

Then we can get the final equation for non-dimensional pressure as follows,

$$dP^+/dt^+ = -(P^+)^{\gamma+1/\gamma}(\{P^+ - P_B^+ + N_p(1+\varphi-\varphi P^{+^{-\gamma}})\}/\{1-P_B^+ + N_p\})^{\frac{1}{2}}. \tag{10}$$

This equation has a unique solution of P^+along the dimensionless time $t^+$when each of the non-dimensional parameters, P_B^+, N_p and φ are uniquely given. For the two cases having different initial pressures, the similarity requires that all the non-dimensional parameters should be the same or should be eliminated from the right-hand side of the Eq. (10). However, one can find such a condition is nearly impossible to achieve. Thus, the similarity on the initial pressure is not guaranteed in general sense.

Fig. 2 shows a representation of non-dimensional pressure along the non-dimensional time of the actual test data conducted in two different initial pressures (KHNP, 2012). As shown in the figure, two curves are not identical all the time period. A similar behavior can be found when $t^+ < 1$, which means isentropic expansion is dominated than the other parameters



a) Overall Configuration b) Lumped Model c) Two-flow path Model

Fig. 1. Configuration of Safety Injection Tank with Fluidic Device and its modeling.