Implicit Safety Injection Tank Model of the SPACE Code and Its Validation

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1. Introduction

Various component models have been incorporated into the Korean pressurized water reactor (PWR) system safety analysis code, SPACE[1]. One of the components is the safety injection tank (SIT) model. It is well known that the SIT plays a key role of emergency core cooling (ECC) water injection into the reactor coolant system (RCS) at the early stage of the loss-of-coolant accident(LOCA). Moreover, the ECC mixing phenomena at around the injection nozzle are very complicated and sensitive. Therefore, the SIT model is necessary to be coupled with the RCS system. In the previous version of the SPACE code, the SIT model used explicit method. In other word, the RCS system and the SIT thermal hydraulics were not solved simultaneously. In the present study, an implicit SIT model is incorporated into the SPACE code in order to overcome the limitation of the previous explicit SIT model. The implicit SIT model and its application results are described in the following sections.

2. Implicit SIT Model

The SIT consists of a cylindrical tank and a discharge pipe at the bottom of the tank. The upper part of the cylindrical tank is filled with the pressurized nitrogen gas, and the remaining lower part of the tank and the discharge pipe are filled with the safety injection water.

In contrast to the explicit model, the implicit SIT model needs to be represented in a differential form of equation in order to obtain the solution coupled with the system thermal hydraulics. The following equations are the differential forms of conservation equations of momentum, mass, and energy for the SIT.

Conservation of momentum is

$$\rho A\left(L\frac{dv}{dt}+\frac{1}{2}v^2\right)+Fv=A\left(P-P_{exit}\right)+A\Delta P_z \tag{1}$$

In the equation (1), A, L, and F denote discharge nozzle area, length of the liquid column, and friction coefficient, respectively. P is the nitrogen dome pressure, and v the liquid velocity at the exit of the discharge pipe. The elevation head, ΔP_z, is obtained by the liquid level above the discharge nozzle.

Continuity equation is described as,

$$\frac{dV_D}{dt}=vA \tag{2}$$

where V_D is the volume of the nitrogen dome.

Conservation of energy is written by the equation (3).

$$P\left(1+\frac{R_n}{C_{V,n}}\right)\frac{dV_D}{dt}+V_D\frac{dP}{dt}=\frac{R_n}{C_{V,n}}\dot{Q}_D \tag{3}$$

where

$$\begin{aligned}\dot{Q}_D &= \left(h_1A_1+h_2A_2\right)(T_w-T_g)+h_2A_2\left(T_f-T_g\right)\\ &\quad +\dot{M}_{vap}h_g^s\left(T_f\right)+\dot{m}_c\left(h_{fg}\left(T_g\right)-h_f^s\left(T_g\right)\right)\end{aligned} \tag{4}$$

In the equation (3), $C_{V,n}$ and R_n denote the specific heat capacity and gas constant of nitrogen gas, respectively. The first term of right hand side of the equation (4) represents the heat transfer between SIT wall and nitrogen gas. The second term is the heat transfer between liquid and gas. The heat transfer area between nitrogen gas, liquid, and wall consist of the area of cylindrical wall, A_1, and the area of top or bottom surface of cylindrical wall, A_2. The enthalpies and temperatures appeared in the equation (4) are as follows:

h_g^s ; Specific enthalpy of saturated vapor
h_f^s ; Specific enthalpy of liquid
h_{fg} ; Latent heat of evaporation
T_g ; Temperature of gas
T_f ; Temperature of liquid
T_w ; Temperature of wall

The third and fourth terms are the evaporation and condensation. Finally, $\dot{M}_{vap}$ gives the vaporization rate at which water vapor is transported into the SIT gas dome by turbulent diffusion, and $\dot{m}_c$ means the rate of condensation at the liquid-gas interface[2].

3. Test Results

The fluidic device performance test conducted by KAERI[3] is chosen to verify the implicit SIT model. The experiment result is compared with those calculated by the implicit SIT model of the SPACE code in the figure 1. Depending on the heat transfer between wall, liquid, and the gas dome, the nitrogen dome pressure behaves in the range between the two extreme cases: isothermal and adiabatic processes. The adiabatic process occurs if the wall and interfacial heat transfer are all neglected. On the other hand, when the heat transfer rate and the heat capacity of wall are assumed to be high enough to maintain the dome temperature at the initial temperature, it becomes isothermal process. As shown in the figure, the experimental data are generally in between the two analyses results for the adiabatic and the isothermal processes.

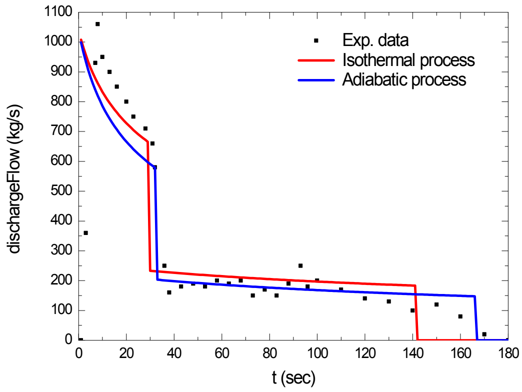

Figure 1. SIT discharge flow rate

In the figure 2, the pressure curves are represented as a function of the volume of nitrogen dome. It can be seen that the pressure curves calculated by the SPACE code agree very well with the analytic solution.

4. Conclusion

An implicit SIT model is incorporated into the SPACE code, and validated for experiment and analytic solutions. The SIT flow and dome pressure calculated by the present model show a good agreement not only with the experimental data but also with the analytic solution. It is expected that the implicit SIT model can be used to simulate safety injection during the blowdown phase of LOCA, instead of the previous explicit SIT model which showed spurious oscillation due to the decoupling with the reactor coolant system.

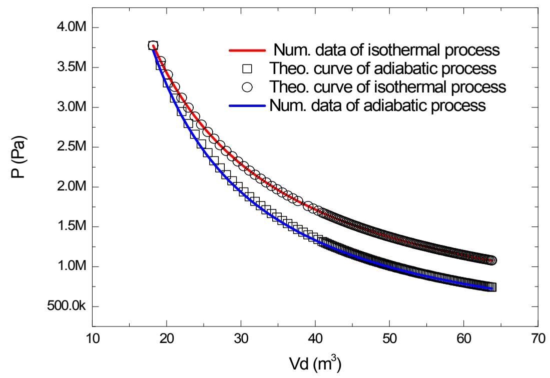

Figure 2. Gas dome pressure as a function of gas volume

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