Parametric Study on Injection Performance of Core Makeup Tank

Soo Jai Shin[a*], Seungyeob Ryu[a], Young In Kim[a]
[a]*Korea Atomic Energy Research Institute, Daedeok-daero 989-111, Yuseong-gu, Daejeon 34057, Republic of Korea*
E-mail: shinsoojai@kaeri.re.kr

1. Introduction

When an accident occurs in a reactor, passive tanks with various types are used to supply emergency cooling water to a reactor vessel. A nitrogen pressurized safety injection tank (SIT) and core makeup tank (CMT) are used in the passive loop type reactors such as AP600, AP1000 and so on. A nitrogen pressurized SIT has been typically designed to quickly inject a high flow rate of coolant when the internal pressure of the reactor vessel is rapidly decreased due to a large break loss of coolant accident (LOCA), and a CMT has been designed to safely inject into the reactor at high pressure using a gravitational head of water subsequent to making a pressure balance between the reactor and tank for the early stages of the accident. The Korea Atomic Energy Research Institute (KAERI) has developed a small modular reactor (SMR) with an integral type pressurized water reactor (PWR), called SMART (System-integrated Modular Advanced ReacTor) [1]. SMART is an integral type reactor where the main components of reactor coolant system (RCS) are directly mounted or integrated without connection using main coolant pipes. Due to the integral arrangement, the possibility of a large break loss of coolant accident (LBLOCA) is inherently eliminated.

We have investigated a performance of the CMT when an small break LOCA (SBLOCA) occurs in a small modular reactor (SMR). This SMR is an integral type reactor similar to SMART with different geometry. A parametric study has been performed to observe the effect of the CMT installation heights on the CMT injection performance.

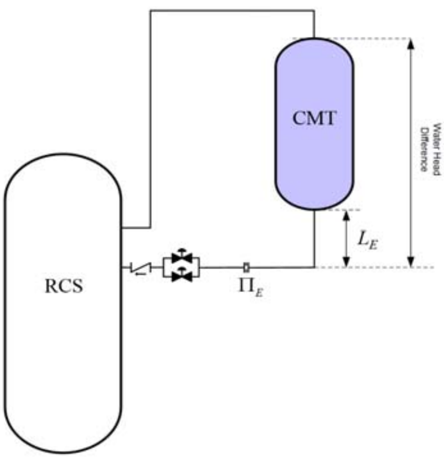

Fig. 1 Schematic of the core makeup tank

2. Model for performance analysis

Figure 1 shows a schematic diagram of the core makeup tank. The top and bottom of the CMT are connected to the RCS through a pressure balance line and a injection line, respectively. The pressure balance line is normally open to maintain the pressure of the CMT at RCS pressure, and this arrangement enables the CMT to inject water into the RCS by gravity when the isolation valve of injection line opens during an SBLOCA. When an accident occurs and the pressure or water level of the reactor vessel drops, the isolation valves installed in the injection line are open by a control signal of the relevant system, and an injection started from the CMT into the reactor vessel.

For thermal hydraulic model of the CMT, the mass conservation, Bernoulli equation, and Darcy formula are used as follows [2]:

$$\rho_L A_{Tank} \frac{dL}{dt} = -\dot{m}_{inj} , \quad (1)$$

$$h_L = \frac{v_E^2}{2g}\left(\frac{fl}{d}+K\right)_E = \frac{v_E^2}{2g}\Pi_E \quad , \quad (2)$$

$$\frac{P_{FS}}{\rho_L g} + z_{FS} + \frac{v_{FS}^2}{2g} = \frac{P_E}{\rho_L g} + z_E + \frac{v_E^2}{2g} + h_L , \quad (3)$$

where ρ_L is the water density, A_{Tank} is the cross-section area of the CMT, $L(t)$ is the water level of the CMT, L_E is the height difference between the injection line and the bottom of the CMT, $\dot{m}_{inj}$ is the injection flow rate, v_E is the velocity of the injection line, f is the friction coefficient of the injection line, and Π_E is the pressure-loss coefficient of the injection line. The water level of the CMT $L(t)$ and the injection flow rate of the CMT $\dot{m}_{inj}$ are obtained by using Eq. (1), (2) and (3):

$$L(t) = \left(\left(L_0 + L_E\right)^{1/2} - \frac{C}{2}t \right)^2 - L_E , \quad (4)$$

$$\dot{m}_{inj}(t) = \rho_L A_{Tank} C \left(\left(L_0 + L_E\right)^{1/2} - \frac{C}{2}t \right), \quad (5)$$

where $C = A_E \big/ A_{Tank} \left(2g/1+\Pi_E\right)^{1/2}$, and L_0 is the initial water level of the CMT. To obtain the RCS pressure and RCS level behavior, the mass conservation equation and depressurization rate equation are used as follows [2]:

$$\frac{dM}{dt} = \sum \dot{m}_{IN} - \sum \dot{m}_{OUT} \,, \quad (6)$$

$$M\left(\frac{\partial e}{\partial P}\right)_v \frac{dP}{dt} = \left(\sum \dot{m}_{IN}\right)\left[h_{IN} - e + v\left(\frac{\partial e}{\partial v}\right)_p\right] - \left(\sum \dot{m}_{OUT}\right)\left[h_{OUT} - e + v\left(\frac{\partial e}{\partial v}\right)_p\right] + \dot{q}_{total} \quad (7)$$

Here, M denotes the total mass inside the RCS, e is the specific internal energy, P is the RCS pressure, $\dot{m}_{IN}$ and $\dot{m}_{OUT}$ are the mass flow rate entering and leaving the RCS, respectively, h_{IN} and h_{OUT} are the enthalpies of the fluid entering and leaving the RCS, respectively, and v represents the specific volume. The total energy transfer $\dot{q}_{total}$ is the summation of the heat removal by core residual heat, RCS structure sensible heat, and heat loss from the RCS

3. Results and discussion

A parametric analysis was performed to investigate the injection performance of the CMT for different CMT installation heights L_E. The total height and the diameter of the present reactor vessel are selected to 15 *m* and 4 *m*, respectively. The water mass in the reactor vessel is selected as 100 *ton*, and the rated thermal power is assumed as 300 *MWt*.. The elevations of the injection line nozzle and pressure balance nozzle from the reactor vessel bottom are selected to 10 *m* and 13 *m*, respectively. The initial RCS pressure is 15 MPa and the initial RCS temperature is 320℃. The level of the core top from the reactor vessel bottom are assumed as 12 m and 4 m, respectively. The other parameters of the CMT are selected as $H_{Tank} = 8\,m$, $D_{Tank} = 4\,m$, D_E = $0.05\,m$, $\Pi_E = 1000$, $\rho_L = 1000\,kg/m^3$. Here, H_{Tank} is the height of the CMT, D_{Tank} is the diameter of the CMT, D_E is the diameter of the injection line.

Figure 2 shows time variations of the CMT injection flow rate, CMT water level for different CMT installation height. When an accident occurs, coolant in the CMT is injected into the reactor vessel through the injection line. As shown in Fig.2, the injection flow rate of the CMT increased and CMT water level decreased faster for larger CMT installation height. Thus, the depletion time of the CMT decreased with increasing the CMT installation height.

Figure 3 shows time variations of the RCS pressure and the RCS level for different CMT installation heights during a 0.05 m piping rupture accident. When an injection line was ruptured, three trains of the CMT were generally actuated from the four CMT trains, excluding the train connected to the ruptured injection line. During a piping rupture accident of the injection line, the RCS pressure was quickly decreased to below the low pressure set-point of the CMT, then the isolation valves in the injection lines are opened, initiating the safety injection from the CMT into the RCS using gravitational head of water. During an initial stage of the LOCA, the RCS level decreased close to the core top (4 m). Then it recovered as the CMT water was injected into the RCS. For larger CMT installation height, the RCS level recovered quickly. Especially for $L_E = 5\,m$, the RCS level quickly recovered to the elevation of the ruptured injection line (10 m) as the CMTs were actuated as shown in Fig. 3. On the other hand, the RCS pressure decreased rapidly regardless of the CMT installation height during a LOCA in Fig. 3.

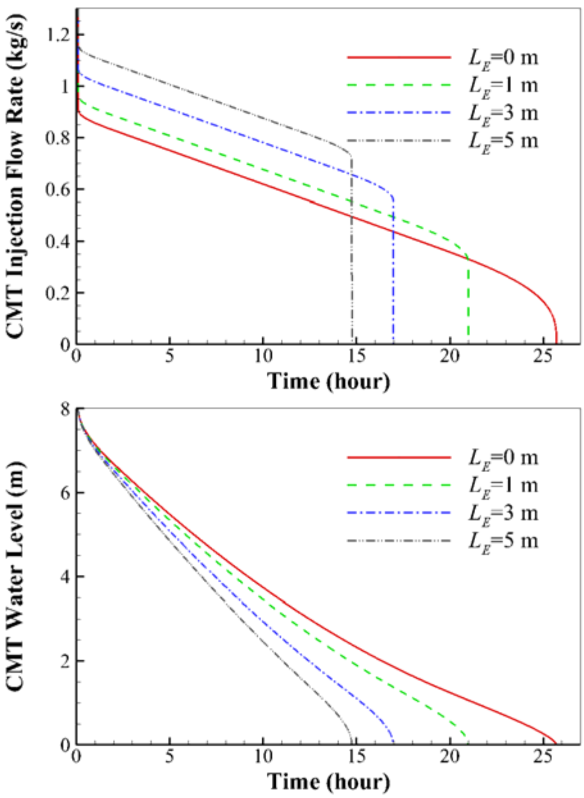

Fig. 2 Time variations of the CMT injection flow rate and CMT water level for different CMT Installation Heights

4. Conclusions

The injection performance of the CMT was investigated numerically, with varying the CMT installation heights. The injection flow rate of the CMT increased with increasing the CMT installation height. The depletion time of the CMT decreased for larger

CMT installation height. The RCS pressure and RCS level behavior during a 0.05 m injection piping rupture accident were also calculated. The RCS pressure decreased rapidly regardless of the CMT installation height during a LOCA. During an initial stage of the LOCA, the RCS level decreased close to the core top. Then it recovered quickly with increasing the CMT installation height.

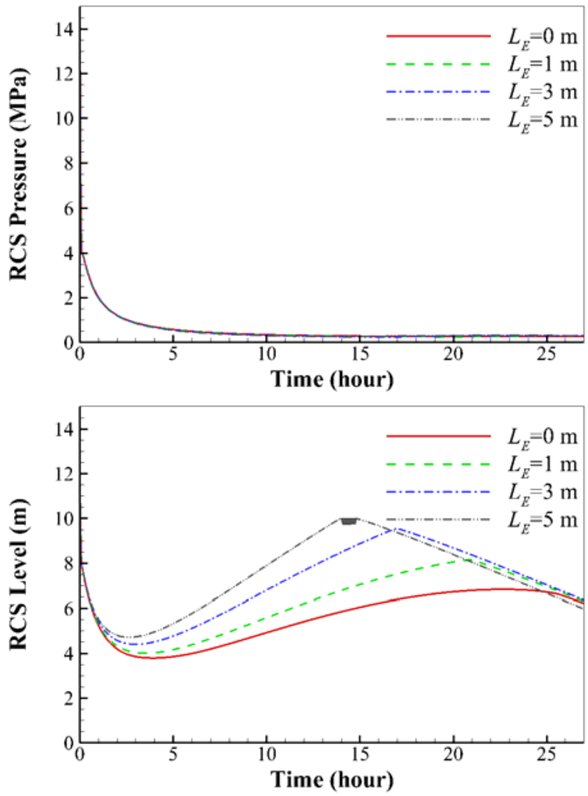

Fig. 3 Time variations of the RCS pressure and RCS level for different CMT Installation Heights

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