Performance Analysis of Two-stage Core Makeup Tank

Soo Jai Shin [a*], Young In Kim [a], Seungyeob Ryu [a], Youngmin Bae [a]
[a]*Korea Atomic Energy Research Institute, Daedeok-daero 989-111, Yuseong-gu, Daejeon 34057, Republic of Korea*
[*]*Corresponding author: 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 and core makeup tank are used in the passive loop type reactors such as AP600, AP1000 and so on. A nitrogen pressurized safety injection tank 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, and a core makeup tank 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. In the present study, we investigate a two-stage core makeup tank, which is designed to inject cooling water into the reactor step by step when an accident occurs. A parametric analysis has been performed to understand the injection performance of the two-stage core makeup tank.

2. Model for performance analysis

Figure 1 shows a schematic illustration of the two-stage core makeup tank. The two-stage core makeup tank consists of a pressure balance line connected to the reactor vessel and the core makeup tank as well as a set of injection lines connected to the core makeup tank and the reactor vessel. As seen in Fig. 1, two injection lines are connected to the core makeup tank at two different heights to reduce the flow rate of coolant injected into the reactor vessel step by step according to the water level reduction of the core makeup tank. The lower injection line is connected to the lower end of the core makeup tank to continuously provide an injection passage for coolant filled within the core makeup tank. The upper injection line is connected to the core makeup tank at location at predetermined height from the core makeup tank bottom to provide injection passages for coolant until the water level of the core makeup tank becomes lower than a predetermined water level. 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 is started from the two-stage core makeup tank into the reactor vessel.

For thermal hydraulic model of two-stage core makeup tanks, the mass conservation, Bernoulli equation, and Darcy formula are used as follows [2] :

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

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

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

where ρ_L is the water density, A_{Tank} is the cross-section area of the core makeup tank, $L(t)$ is the water level of the core makeup tank, L_E is the height difference between the lower injection line and the bottom of the core makeup tank, $\dot{m}_{inj}$ 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 core makeup tank $L(t)$ and the injection flow rate of the core makeup tank $\dot{m}_{inj}$ are obtained by using Eq. (1), (2) and (3):

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

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

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 core makeup tank.

3. Results and discussion

A parameter analysis was conducted to assess the performance of the two-stage core makeup tank. Note that H_{Tank} is the height of the core makeup tank; D_{Tank} is the diameter of the core makeup tank; D_E is the diameter of the injection line; L_1 is the height difference between the upper injection line and the bottom of the core makeup tank; and $\Pi_{E,1}$ and $\Pi_{E,2}$ are the pressure-loss coefficients of the upper and lower injection lines, respectively. The input parameters for the analysis are summarized in Table 1, As seen in Table 1, the value of $\Pi_{E,2}$ is larger than that of $\Pi_{E,1}$. Accordingly, the total flow resistance is increased step by step according to the water level reduction of the core makeup tank to decrease the flow rate of coolant injected into the reactor vessel. The other parameters are selected as $\rho_L = 1000\,kg/m^3,\ H_{Tank} = 8\,m,\ D_{Tank} = 4\,m,\ D_E = 0.05\,m$ $L_E = 5\,m$.

Figure 2 shows time variations of the water level and injection flow rate of the two-stage core makeup tank for case 4, where $L_0 = 8,\ L_1 = 4,\ \Pi_{E,1} = 2000,\ \Pi_{E,1} = 5000$. When an accident occurs, coolant within the core makeup tank is injected into the reactor vessel through the upper and lower injection lines. The total flow resistance of the injection lines is lower when coolant is injected through the two passages of the upper and lower injection lines than when coolant is injected through only one passage of the lower injection line, and coolant is injected at a higher flow rate into the reactor vessel when an accident occurs during the initial stage. The gravitational head of water is gradually decreased by the water level reduction of the coolant until the coolant level of the core makeup tank is reduced lower than the upper injection line (L_1 =4); therefore, the flow rate of coolant injection is gradually reduced. Then, the flow rate of coolant injection is instantaneously and rapidly reduced when the coolant level of the core makeup tank is reduced lower than the upper injection line (L_1 =4). The coolant is not injected through the upper injection line. therefore, injection from the core makeup tank into the reactor vessel is carried out only through the lower injection line. Thus, injection is conducted at a lower flow rate. The flow resistance when coolant is injected only through one passage of the lower injection line is higher than when coolant is injected through the two injection lines. Thus, injection at a low flow rate can be carried out for a long period of time. The low-flow-rate injection continues until most of the coolant of the core makeup tank is injected into the reactor vessel, and the injection time can be adjusted according to the design of the core makeup tank.

Table I: Input parameters for the performance test

	L_0	L_1	$\Pi_{E,1}$	$\Pi_{E,2}$
Case 1	8	6	1000	5000
Case 2	8	4	1000	5000
Case 3	8	2	1000	5000
Case 4	8	4	2000	5000
Case 5	8	4	2000	10000

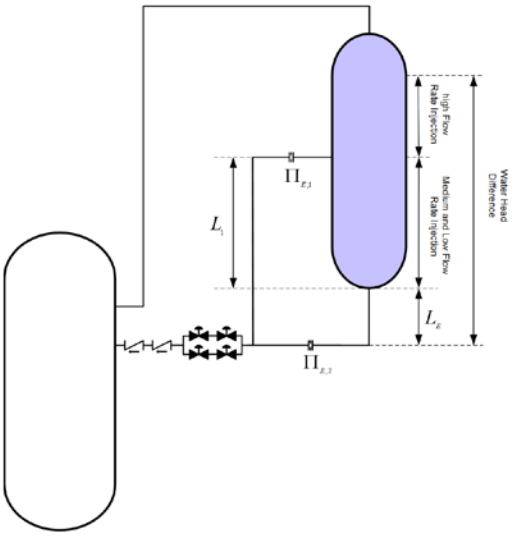

Fig. 1 Schematic of two-stage core makeup tank

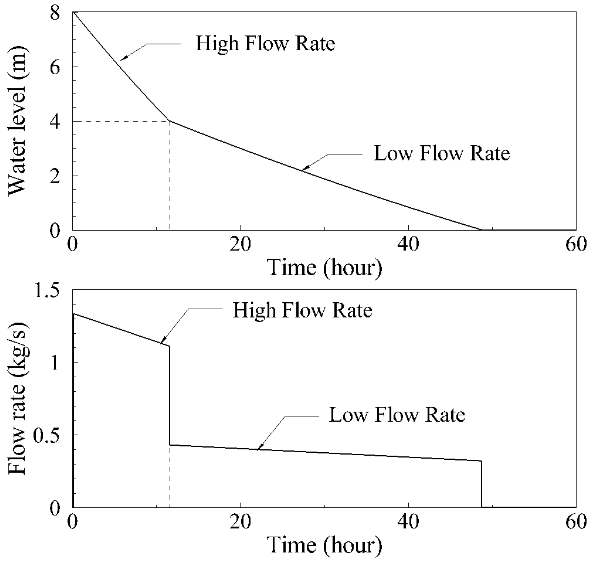

Fig. 2 Time variations of the water level and injection flow rate of the two-stage core makeup tank

3. Conclusions

The performance of the two-stage core makeup tank was investigated numerically. When an accident occurs, the coolant in the two-stage core makeup tank is injected into the reactor vessel by a gravitational head of water in a pressure balance state between the reactor vessel and the core makeup tank. At the early stages of the accident, coolant from the two-stage core makeup tank is injected at a high flow rate into the reactor. Subsequently, coolant is injected at a low flow rate for a long period of time at the middle and late stages of the accident. The two-stage core makeup tank is capable of injecting coolant into a reactor vessel by two step according to the characteristic of injection required when a reactor accident occurs.

ACKNOWLEDGEMENTS

This work was supported by the Korea Atomic Energy Research Institute(KAERI) grant funded by the korea government.

REFERENCES

[1] Y.I. Kim, K.K. Kim, C.T. Park, S.Y. Yoo, Y.M. Bae, J.H. Moon, S.J. Shin, H.O. Kang, J. Lee, W.J. Lee, T.W. Kim, K.B. Park, J.H. Yoon, Multi stage safety injection device and passive safety injection system having the same, US Patent App. 14/172808.
[2] J.N. Reyes Jr., AP600 and AP1000 passive safety system design and testing in APEX, IAEA-TECDOC-1474, 2005.