Performance Analysis of Multi Stage Safety Injection Tank

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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 is used for rapidly supplying coolant to a reactor during a large break loss of coolant accident. A core makeup tank using a gravitational head of water subsequent to making a pressure balance between the reactor and tank is used in addition to a nitrogen pressurized safety injection tank in AP600, AP1000 and so on.

In general the integral reactor has such characteristics, the integral reactor requires a high flow rate of coolant safety injection at the initial stage of the accident in which the core level is relatively fast decreased, A medium flow rate of coolant safety injection at the early and middle stages of the accident in which the coolant discharge flow rate is relatively large due to a high internal pressure of the reactor vessel, and a low flow rate of coolant safety injection is required at the middle and late stages of the accident in which the coolant discharge flow rate is greatly reduced due to a decreased pressure of the reactor vessel. It is noted that a high flow rate of the integral reactor is quite smaller compared to a flow rate required in the commercial loop type reactor. However, 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, and a core makeup tank has been designed to safely inject at a single mode flow rate due to a gravitational head of water subsequent to making a pressure balance between the reactor vessel and core makeup tank. As a result, in order to compensate such a disadvantage, various type systems are used in a complicated manner in a reactor according to the required characteristic of safety injection during an accident. For example, a pressure balance core makeup tank, a pressurized safety injection tank, an in-containment refueling water storage tank are used in a passive pressurized water reactors AP600, AP1000. Recently, Kim et al. [1] proposed a new safety injection tank which is capable of injecting coolant with a single tank in multiple stages according to the safety injection characteristics required for a reactor.

In the present study, we have investigated numerically the performance of the multi stage safety injection tank. A parameter study has performed to understand the characteristics of the multi stage safety injection tank.

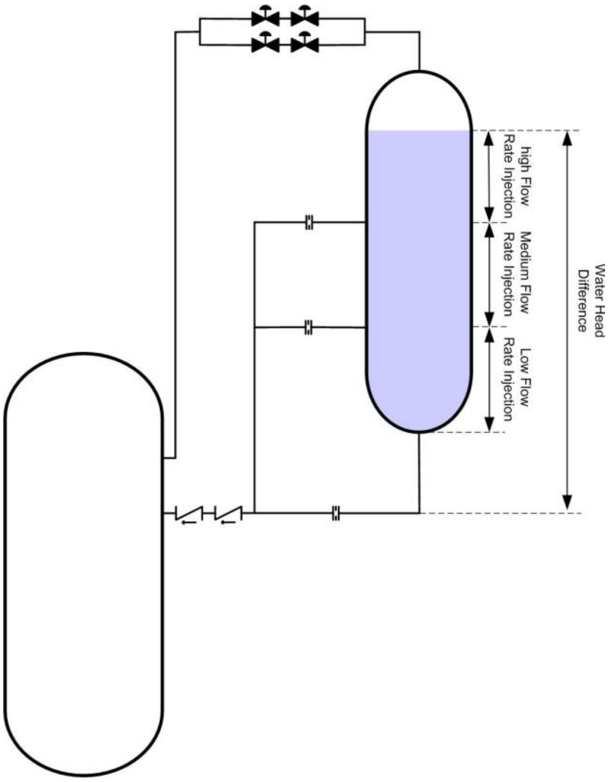

Fig.1. Schematic of a multi stage safety injection tank.

2. Model for performance analysis

Figure 1 illustrates the multi stage safety injection tank. The multi stage safety injection tank consists of a pressure balance line connected to the reactor vessel and the safety injection tank, and a set of safety injection lines connected to the safety injection tank and the reactor vessel. As shown in Fig. 1, the safety injection lines are connected to the safety injection tank with different heights to reduce a flow rate of coolant injected into the reactor vessel step by step according to the water level reduction of the safety injection tank. The lowest safety injection line is connected to a lower end part of the safety injection tank to continuously provide an injection passage for coolant filled within the safety injection tank. The middle and uppermost safety injection line is connected to the safety injection tank at a location higher by a predetermined height from the lowest safety injection line to provide an injection passage for coolant until the water level of the safety injection tank becomes lower than a predetermined water level.

The mass conservation, Bernoulli equation, Darcy formula are as follows [2],

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

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

$$h_L = \frac{v_E^2}{2g}\left(\frac{fl}{d}+K\right)_E = \frac{v_E^2}{2g}\Pi_E \qquad (3)$$

Where ρ_L is the water density, A_{Tank} is the cross section area of the safety injection tank, $L(t)$ is the water level of safety injection tank, L_E is the height difference between the lowest safety injection line and the bottom of the safety injection 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 safety injection line, Π_E is the pressure drop coefficient of the safety injection line, respectively. The water level of the safety injection tank $L(t)$ and injection flow rate of the safety injection 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 $C = A_E / A_{Tank}\left(2g/1+\Pi_E\right)^{1/2}$, L_0 is the initial water level of the safety injection tank.

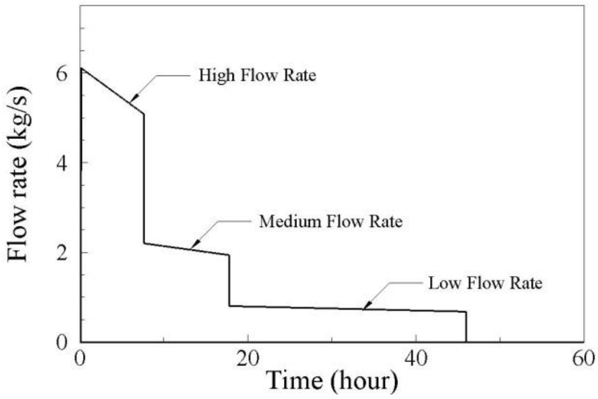

Fig.2. time variations of the injection flow rate of coolant in the multi stage safety injection tank.

3. Results and discussion

A performance test has been performed to observe the characteristics of the multi stage safety injection tank. The input parameters for the test are summarized in Table I, where H_{Tank} is the height of the safety injection tank, D_{Tank} is the diameter of the safety injection tank, D_E is the diameter of the safety injection line, L_1 is the height difference between the uppermost safety injection line and the bottom of the safety injection tank, L_2 is the height difference between the middle safety injection line and the bottom of the safety injection tank, $\Pi_{E,1}, \Pi_{E,2}, \Pi_{E,3}$ is the pressure drop coefficient of the uppermost, middle, lowest safety injection line, respectively. As shown in table I, the value of $\Pi_{E,2}$ is larger than $\Pi_{E,1}$ and the value of $\Pi_{E,3}$ is largest in the set of safety injection lines. Accordingly, a total flow resistance is increased step by step according to the water level reduction of the safety injection tank to decrease a flow rate of coolant injected into the reactor vessel.

Figure 2 shows time variations of the injection flow rate of coolant in the multi stage safety injection tank. The multi stage safety injection tank is capable of injecting coolant into a reactor vessel step by step when a reactor accident occurs. When an accident occurs in which the pressure or water level of the reactor vessel is decreased, a pressure balance line connected to the reactor vessel and safety injection tank to form a pressure balance state between the reactor vessel and the safety injection tank. After that the coolant is injected into a reactor vessel by a gravitational head of water in a pressure balance state balance between the reactor vessel and the safety injection tank. As shown in Fig. 2, the high flow rate of coolant is injected within a short period of time when an accident occurs. Subsequently, a medium flow rate of coolant is injected at the early and middle stages of the accident. Finally, a low flow rate is injected for a long period of time at the middle and late stages of the accident. As shown in Fig. 2, the coolant can be continuously injected without a problem of delay or overlap in the coolant injection during the process of flow rate switching.

Table I: Input Parameters for the Performance Test.

Parameter	Unit	Value
ρ_L	Kg/m^3	1000
H_{Tank}	m	10
D_{Tank}	m	4
D_E	m	0.05
L_0	m	8
L_1	m	4
L_2	m	2
L_E	m	5
$\Pi_{E,1}$	-	1000
$\Pi_{E,2}$	-	5000
$\Pi_{E,3}$	-	10000

4. Conclusions

The performance of the multi stage safety injection tank has been investigated numerically. When an accident occurs, the coolant in the multi stage safety injection tank is injected into a reactor vessel by a gravitational head of water subsequent to making a pressure balance between the reactor and tank. At the early stages of the accident, the high flow rate of coolant in the multi stage safety injection tank is injected into a reactor. Subsequently, a medium flow rate of coolant is injected at the early and middle stages of the accident. Finally, a low flow rate is injected for a long period of time at the middle and late stages of the accident. The multi stage safety injection tank is capable of injecting coolant into a reactor vessel step by step according to the required characteristic of safety injection when a reactor accident occurs.

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.