Gravity Driven Injection Velocity of Hybrid SIT

Tae-Soon Kwon*, D. J. Euh, C.K. Park
Korea Atomic Energy Research Institute, P.O.Box 105, Yuseong, Daejon, 305-600, Korea
**Corresponding author: tskwon@kaeri.re.kr*

1. Introduction

The recent Fukushima nuclear power plant accidents shows that the core make up at high RCS pressure condition is very important to prevent core melting. The core make up flow should be driven by gravity force or passive forces because the AC-powered safety features are not available during the Station Black Out (SBO) accident. The RCS mass inventory is continuously decreased by releasing steam through the pressurizer safety valves after reactor trip. The core will be melted down within 2~3 hours without core make up action.

In the new design concept of a Hybrid Safety Injection Tank (HPSIT) both for low and high pressure conditions, the low nitrogen gas serves as a charging pressure for a LOCA injection mode, while the PZR high pressure steam provides an equalizing pressure for a high pressure injection mode such as SBO[1]. After the pressure equalizing process by battery driven valve at high pressure SBO condition, the HPSIT water will be passively injected into the reactor downcomer by gravity head.

2. Design Concept

2.1 Current Design

The CARR and AP600 have SITs and CMTs combined safety system [2,3]. The SITs are for a low pressure LOCA condition, and are pressurized by nitrogen gas. The CMTs are for a high pressure LOCA condition, and are pressurized by the PZR or RCS pressure. However, the CMT does not supply a high flow rate to refill the reactor vessel during a low pressure LOCA situation.

2.2. HPSIT

Figure 1 shows a schematic diagram of the HPSIT. The equalizing valve is a battery driven valve for the SBO condition. The 4 SITs are designed for the high pressure and high temperature conditions (the pressurizer design condition). The HPSIT conserved the high safety injection flow characteristics for the low pressure LOCA because the SIT was charged with a low pressure nitrogen gas, while the HPSIT supplies the core makeup flow by the gravitational head after the HPSIT is pressurized by the steam pressure of the PZR at a high pressure SBO condition.

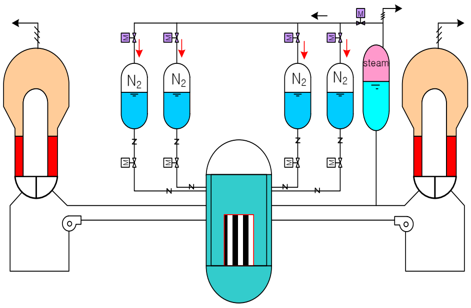

Fig. 1 Hybrid HPSIT

3. Gravity Driven Injection Velocity

The gravity driven injection velocity of the HPSIT at an injection nozzle (DVI nozzle) is evaluated by an analytical method. As shown in Fig. 2, the RCS has an initial water head **at the given working conditions**. The RCS pressure reaches the set pressure of the PZR safety valves, and then goes on hysteresis mode by the safety valve on/off actuation. The RCS inventory decreases during above safety valve hysteresis mode.

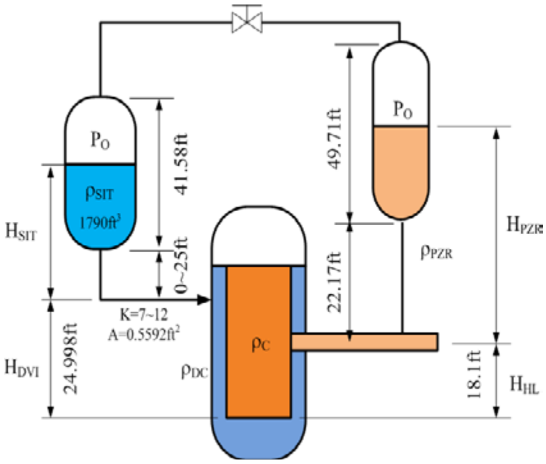

Fig. 2 HPSIT pressure network

The Euler equation for the HPSIT side is,

$$P_O + \rho_{SIT} H_{SIT} g = P_1 + H_{Loss} + \tfrac{1}{2} \rho_{SIT} V_{Inj,DVI}^{\ 2} \qquad (1)$$

and, for the RCS side,

$$P_O + \rho_{PZR} H_{PZR} g + \rho_C H_{HL} g = P_1 + \rho_{DC} H_{DVI} g \qquad (2)$$

Substituting Eq. (1) into Eq. (2) gives the following relationships for, the velocity and the head:

$$(f\,{}^{L}\!/\!_{D} + K + 1)\frac{1}{2g}V_{Inj,DVI}{}^{2} = H_{SIT} - \frac{\rho_{PZR}}{\rho_{SIT}}H_{PZR} - \frac{\rho_{C}}{\rho_{SIT}}H_{HL} + \frac{\rho_{DC}}{\rho_{SIT}}H_{DVI} \quad (3)$$

where,

$$H_{Loss} = (f\,{}^{L}\!/\!_{D} + K)\,{}^{1}\!/\!_{2}\,\rho_{SIT}V_{Inj,DVI}{}^{2}$$

Thus, the injection velocity discharged from SIT is.

$$V_{Inj,DVI} = \left\{\frac{2g}{f\,{}^{L}\!/\!_{D} + K + 1} * H\right\}^{1/2} \quad (4)$$

Where,

$$H = \left[H_{SIT} - \frac{\rho_{PZR}}{\rho_{SIT}}H_{PZR} - \frac{\rho_{C}}{\rho_{SIT}}H_{HL} + \frac{\rho_{DC}}{\rho_{SIT}}H_{DVI}\right]$$

If we assume, $\rho_C \approx \rho_{PZR}$, then the final velocity can be obtained using the following relationship for H:

$$H = \left[H_{SIT} - \frac{\rho_{PZR}}{\rho_{SIT}}(H_{PZR} + H_{HL}) + \frac{\rho_{DC}}{\rho_{SIT}}H_{DVI}\right]$$

3.1 Injection velocity at pressure equivalence

The initial gravity driven injection velocity by HPSIT is dependent on the water head and density differences. The water level of HPSIT and PZR are at the nominal condition. The dome pressure of SIT and PZR is equivalence after the connection valve opening. The evaluated injection velocity gives:

$$V = \left(\frac{2*9.81}{0.012*25*{}^{12}\!/\!_{8.5} + 12 + 1} * 0.304\left[27.72 - \frac{565}{990}(24 + {}^{49}\!/\!_{2} + 18.1) + \frac{565}{990}24.998\right]\right)^{1/2} \quad (5)$$

=1.47 m/s

Where,

K=7~12
H_{SIT}=27.72 ft (for FSAR 1790ft^3)
H_{DVI}=24.998 ft
H_{HL}=18.1 ft
H_{PZR}=22.17 ft for PZR Empty condition
H_{PZR}=(22.17 +49.1*0.5)ft for nominal PZR condition
D_{DVI}=8.5 inch
L=25ft
ρ_{PZR} =565 kg/m^3, at 17 MPa saturated condition
ρ_{SIT} =990 kg/m^3,

3.2 Injection velocity at PZR empty

For the delayed opening of the connection valve, the water level of PZR is at the bottom. The dome pressures of HPSIT and PZR are also equivalence after the connection valve opening. The evaluated injection velocity gives:

$$V_{Inj,DVI} = \left(\frac{2*9.81}{0.012*25*{}^{12}\!/\!_{8.5} + 12 + 1} * 0.304\left[27.72 - \frac{565}{990}(24 + 18.1) + \frac{565}{990}24.998\right]\right)^{1/2} \quad (6)$$

=2.91 m/s

3.3 Design Limit of HPSIT Elevation

The elevation of the HPSIT is limited for the gravity driven injection. The relative elevation of HPSIT should be higher than that given by H_{SIT}, $for, V_{Inj} > 0$

$$H_{SIT} > \frac{\rho_{PZR}}{\rho_{SIT}}(H_{PZR} + H_{HL}) - \frac{\rho_{DC}}{\rho_{SIT}}H_{DVI}$$

4. Conclusions

In order to verify the effectiveness of the HPSIT design feature to mitigate the SBO accident, the gravity driven injection velocity of the HPSIT at the injection nozzle(DVI) is evaluated analytically.

Acknowledgement

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