Analysis of Thermal-Hydraulic Behavior of CMT in the SMART-ITL Facility

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1. Introduction

To ensure integrity of a nuclear core under prolonged station blackout, a variety of passive systems have been developed so far. One way is to use core makeup tanks to inject coolant into the reactor vessel via gravity. SMART, an integral small modular reactor, received a standard design approval in 2012 and now extends its safety features through replacing active safety injection pumps by passive safety injection systems: core makeup tanks (CMT) and safety injection tanks (SIT) [1]. SMART-ITL has been built in a full height scale and 1/49 area and power scale [2]. One train of CMT and SIT has been installed and their thermal-hydraulic behaviors have been identified through a series of tests [3, 4]. In this paper, initial condensation characteristics as well as force balance around the CMT will be discussed for a representative test.

2. Description on the experiment

The schematic of SMART-ITL facility is displayed in Fig. 1. The facility comprises of a primary system, a secondary system, 4 steam generators, 4 trains of a passive residual heat removal system (PRHRS), and 4 trains of an active safety system, 2 trains of a shutdown cooling system, a break simulator, a break flowrate measuring system, and an auxiliary system. 1 train of a passive safety injection system (PSIS) and 2 stages of an automatic depressurization system (ADS) were added. Fig. 2 shows the schematic of PSIS. The top of CMT and SIT are connected to the upper downcomer of the reactor pressure vessel through a pressure balance line (PBL). This feature allows prompt injection of coolant regardless of reactor pressure whereas common accumulators are restricted by the reactor pressure. One isolation valve is closed at the bottom of the CMT, i.e. at the injection line. Once a reactor is tripped because of low pressurizer pressure (LPP) after a small break loss of coolant accident (SBLOCA), the isolation valve is opened to begin CMT injection. Regarding the operation of CMT, main issues can be summarized in two: 1) fierce condensation of steam after the opening of the isolation valve and 2) suspension of injection because of pressure drop along PBL and condensation inside the CMT.

The first issue comes from fierce condensation when steam from the reactor pressure vessel comes across the cold water in CMT. The fierce condensation leads to sudden drop of pressure inside CMT for a significant period of time preventing safety injection. The phenomenon has been experimentally observed and direct contact condensation regime map is made [5, 6]. As a resolution, a sparger or flow distributor is installed at the injection nozzle for AP600 as well as for SMART.

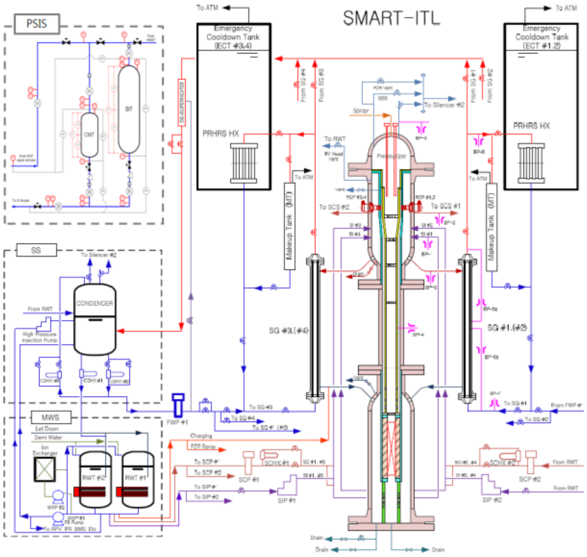

Fig.1 Schematic of SMART-ITL facility

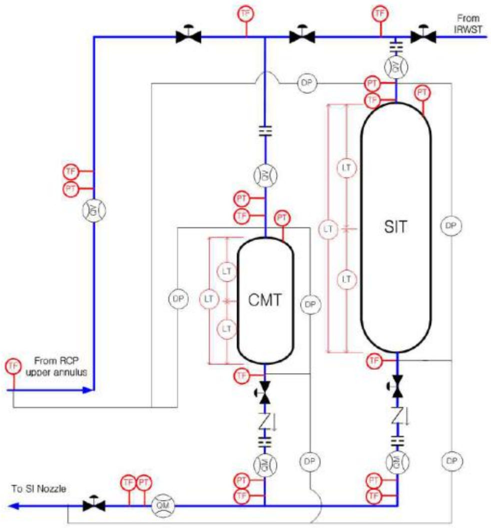

Fig.2 Schematic of SMART-ITL PSIS

The second issue is related to low driving force of PSIS, an intrinsic and significant characteristic to all passive systems that should be finely examined. Small pressure drop, either from friction or condensate along the pressure balance line, can hamper driving force of the injection.

The test scenarios we are dealing with are S100 and S108, where SBLOCA is simulated [4]. The main difference between the two is the presence of the flow distributor: no flow distributor for S100 and a flow distributor for S108.

3. Initial behavior of CMT

Fig. 3 shows the trend of CMT injection flow rate at the early phase. We can see that, regardless of slight difference in initial flow rates, the injection is well made for both S100 and S108 tests. The pressure inside the CMT is not abruptly dropped along the same period. This stable operation of CMT at the initial contact of steam with the cold water is different from the observation from previous experiments that target application to AP600. The main reason has to do with the steam velocity. Table 1 compared the steam injection velocities along the PBL obtained from three experiments. In SMART-ITL, the velocity is significantly smaller than those from previous tests that showed fierce condensation without spargers or flow distributors. In AP600, the CMT water should be injected into the reactor very fast because of possible large break loss of coolant accident (LBLOCA) [7]. On the other hand, SMART does not have any LBLOCA because the reactor has the integral characteristics. Therefore, the required injection flow rate for SMART is much lower than that for AP600. Furthermore, the pressure at steam injection is different: above 9.0 MPa for SMART-ITL and 2.0 MPa for PACTEL. This difference in pressure leads to big difference in steam density: 50 kg/m^3 for SMART-ITL and 10 kg/m^3 for PACTEL. Because the steam velocity is obtained by G/ρ, where G and ρ represent mass flux and density, the steam velocity becomes slow for SMART-ITL conducted at high pressure.

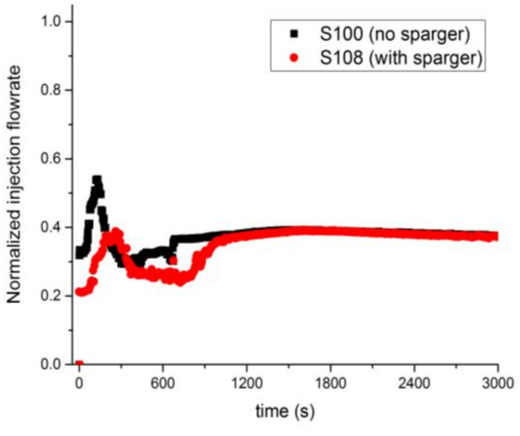

Fig.3 Normalized CMT injection flowrate after opening the isolation valve

Table1Comparison of steam injection velocity among various experiments

	SMART-ITL [4]	PACTEL [5]	KAIST [6]
Steam velocity (m/s)	0.9	36	> 45

4. Force balance around CMT

Fig. 4 represents the CMT injection rates for the S108 test. We can see that the CMT water drops for a while and then is suspended at a certain level. It is attributed to the force balance between the gravimetric driving force and the suppressing force from the pressure drop along the PBL. Each force is compared with the injection flow rate in Fig. 5. We can see that the driving force is decreased as CMT level is decreased while suppressing force is maintained at a certain level. When the driving force equals the suppressing force, the flow injection is stopped. Detailed analysis on the suppressing force of pressure drop along the PBL as well as the resolutions is in progress.

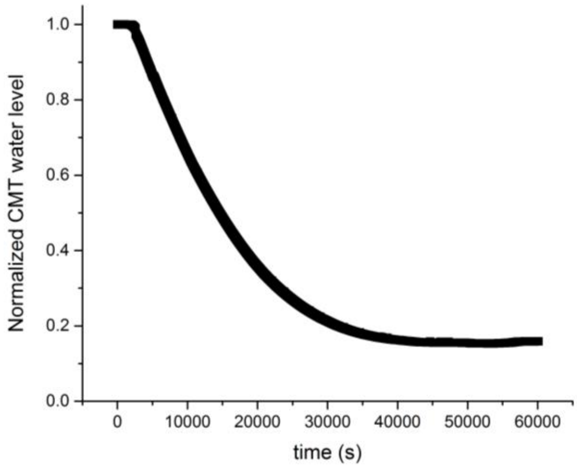

Fig. 4 Normalized CMT water level trend for the S108 test

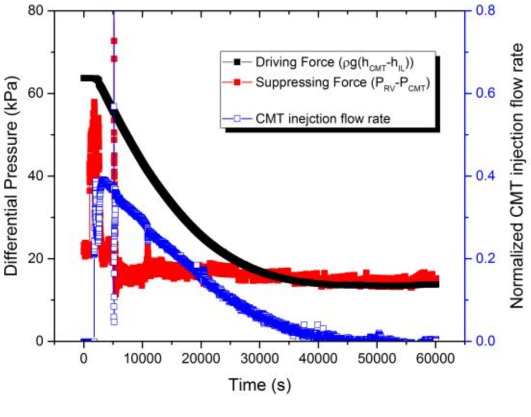

Fig. 5 Force balance around CMT overlapped on the CMT injection flowrate for the S108 test

5. Conclusions

PSIS are added into SMART for better treatment of accidents with prolonged station blackout. In the SMART-ITL, the CMT and SIT are installed to evaluate their performance and a series of tests have been conducted. In this paper, the thermal-hydraulic behavior of CMT is addressed based on the experimental data, especially focusing on the issues of fierce condensation after opening of the isolation valve and driving force balance around the CMT. We found out that the fierce condensation and following cessation of injection do not happen in SMART-ITL, or SMART, because the steam velocity inside the PBL is small compared with AP600. The study on force balance showed that the pressure drop along the PBL can lead to the suspension of CMT injection. More discussion on the suppressing force is in progress.

Acknowledgments

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