Steady-State and Transient Analysis for Design Validation of SMART-ITL Secondary System

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1. Introduction

SMART is a small-sized integral modular reactor containing the main components including steam generators (SGs), a pressurizer (PZR), and reactor coolant pumps (RCP) without large-size pipe system [1]. Because of these design features, SMART can prevent large-break loss of coolant accident (LBLOCA) inherently. SMART-ITL is an experimental simulation facility designed to perform integral effect tests for the SMART plant [2].

In terms of the secondary system of SMART-ITL, the design has been simplified from that of reference plant by replacing several components, such as expansion device and condenser, with an appropriate device to be functional as the alternatives. In this paper, in order to understand the operational characteristics as well as design concept, the secondary system of SMRAT-ITL is analyzed in steady-state and transient aspects, and the results are compared with relevant experimental results.

2. Description of Facility

Fig. 1 shows the schematic of SMART-ITL facility including primary and secondary systems. The major states in cycle process are indicated as the large circular numbers. The secondary system mainly comprises two loops, main feedwater (MF) and condenser (CD) loops, with several components including a condensation tank, four steam generators, two heat exchangers, and two feedwater pumps. The condensation tank (TK-CD-01) is implemented as both of condenser and fluid reservoir. The main steam is condensed at the upper part of the condensation tank on the basis of the direct-contact heat transfer with recirculation water. For raising the condensation effect, the sparger is installed at the top of condensation tank. The condensate is accumulated at the lower part of condensation tank. Basically, the main objective of SMART-ITL secondary system is to realize the steady-state condition as the normal-operation condition as well as initial test condition of accident simulation. Therefore, the system should be capable of regulating the pressure and temperature of main feedwater as targeted condition as well as maintaining the system to be stable before triggering the sequence of event (SOE). The temperatures of feedwater and recirculation water could be controlled by regulating the amount of heat transfer at HX-CD-01 and HX-CD-02, respectively. Feedwater pumps are used to control the flow rate for corresponding loops.

3. Steady-state Analysis

To identify the precise behaviors of the secondary system, the steady-state analysis was carried out based on an experimental result. During the experiment, the system has been carefully controlled to reach the targeted condition, and remained as the steady-state condition for more than 1400 seconds.

The temperatures at each state corresponding to Fig. 1 are averaged, and plotted in Fig. 2 as the sequence of cycle process. The saturation temperatures based on the pressure measured at MF and main steam (MS) loops are also presented in Fig. 2. Since the secondary system doesn't have any expansion devices such as expansion valve and turbine, the pressure difference throughout the entire system is insignificant unlike in the case of general Rankine cycle. The temperatures at the upper and lower parts of TK-CD-01 are similar to each other. This means that the upper part of TK-CD-01 filled with saturated vapor which imposes the fluid in lower part of TK-CD-01 to be sufficiently pressurized as well as to be remained as saturated liquid. Fig. 3 shows the T-s diagram for steady-state condition of SMART-ITL secondary system based on the experimental results. The entire cycle process proceeds at nearly constant pressure of about 5.2 MPa. Moreover, the temperature profiles established between secondary fluid and its source for each process are clearly identified in T-s diagram.

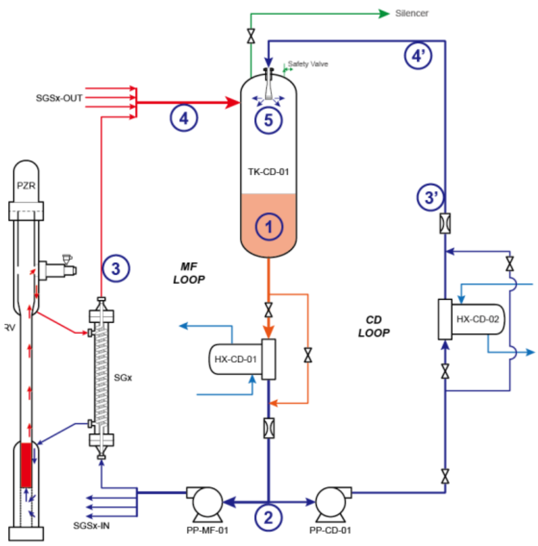

Fig. 1. Schematic diagram of SMRAT-ITL including primary and secondary systems.

Large superheating of the main steam at the outlet of steam generators is observed. Even though the vapor temperature is quite lowered after the main steam line, the vapor still has enough degree of superheating. The recirculation water temperature is appropriately lowered for the sufficient condensation of the main steam.

4. Transient Analysis

To predict the transient behaviors of temperature and pressure of the secondary system during heat-up process, the lumped heat transfer model was employed with several assumptions. The model is focused on the TK-CD-01 separated into 3 control volumes, where the energy and mass conservation equations are applied. In this model, the fluid filled in TK-CD-01 is assumed to be saturated liquid and vapor because those phenomena have been empirically observed in experiments. Fig. 4 and Fig. 5 show measured and calculated temperatures and pressure at TK-CD-01, respectively. As shown in the figures, the variation trend between temperature and pressure is similar to each other. In addition, the results from calculation are very close to those from measurements.

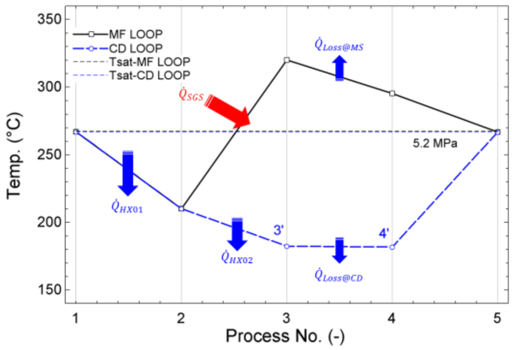

Fig. 2. Temperature measured at steady-state as the sequence of cycle process

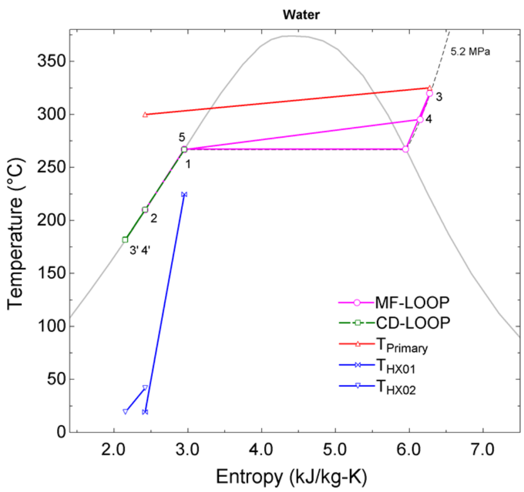

Fig. 3. T-s diagram for steady-state condition of SMART-ITL secondary system

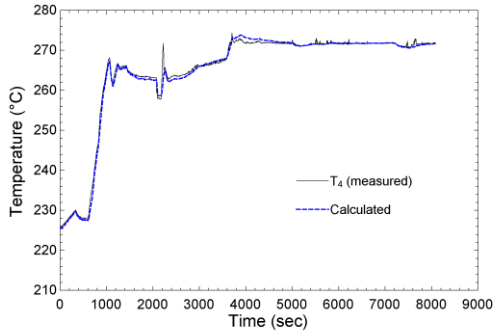

Fig. 4. Measured and calculated temperatures at TK-CD-01

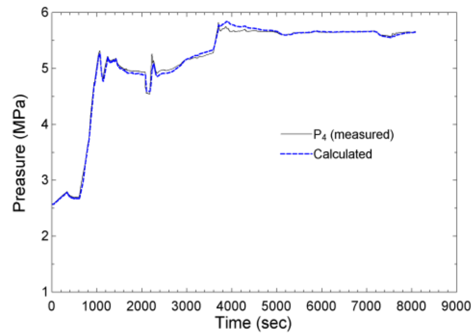

Fig. 5. Measured and calculated pressures at TK-CD-01

5. Conclusions

This study focuses on the understanding of thermal-hydraulic behavior of SMART-ITL secondary system, which is simplified from that of reference plant. To identify the behaviors of the secondary system, the steady-state and transient analysis were conducted based on experimental results. In steady-state analysis, the results clearly showed that the system pressure is related to the temperature of condensation tank which varies depending on mixture enthalpy. In transient analysis, the dynamic behavior during heat-up process has been investigated. The results reveal that we can reasonably assume the fluid filled in TK-CD-01 be in a saturated condition. The results showed that the design of SMART-ITL secondary system is appropriate, and the system is being properly operated to match the design intent.

ACKNOWLEDGEMENT

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