Conceptual Validation Tests on Condensation during Natural Circulation using SISTA

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1. Introduction

When one of representative design basis accidents (DBAs), such as small break loss-of-coolant accident (SBLOCA), occurs in the integral type reactor, SMART [1], both steam and radioactive material are ejected into low containment area (LCA) of the containment pressure and radioactivity suppression system (CPRSS) [2]. Consequently, pressurized LCA leads to steam condensation and radioactive material resolution in in-containment refueling water storage tank (IRWST) and radioactive material removal tank (RRT). Non-condensable (NC) gas also moves from the LCA to upper containment area (UCA) passing through the IRWST and the RRT.

There are two flow paths from the LCA to the IRWST. One is direct discharge of mixture to IRWST via pressure relief line (PRL) and consequent direct contact condensation. The other is bypass discharge through CPRSS heat exchanger (CHX) in the emergency cool-down tank (ECT) partially removing the residual heat. Discharge through the first flow path stops working shortly after the break, while discharge through the second flow path lasts for long term cooling operation over than 3 days.

The steam and NC gas mixture pass through CHX during the whole CPRSS operation due to initial NC gas in the LCA. During the CPRSS operation, condensation heat transfers occur in the CHX under the conditions of forced convection and natural circulation depending on the released steam amount according to the residual heat. The NC gas can interrupt condensation heat transfer in the CHX. Because it makes CHX performance degraded, conceptual validation tests associated with NC gas fraction effect should be conducted.

In this study, condensation heat transfer tests of pure steam and NC gas mixture in the vertical-tube with natural circulation conditions were carried out to validate CPRSS conceptual design.

2. Condensation Experiment in Closed Loop

In this section the features of test facility, test conditions and temperature distribution in CHX are described.

2.1 Features of Test Facility

The SMART IRWST separate effect test apparatus (SISTA) was constructed following main components of CPRSS such as LCA, ECT, CHX, IRWST, RRT, and UCA [2]. It was scaled down using Ishii's scaling method (1:5,000 volume scale) [3]. The components and configuration of SISTA are presented in Fig. 1. The detail of SISTA facility is explained in the previous study [2]. This paper briefly describes the components used in the natural circulation condensation experiments.

The fluid system to be used for the natural circulation condensation experiments is shaded in the Fig. 1. This part was used selectively among the whole system of SISTA for the experiments. There are steam generators (HPZR or SST), LCA, ECT, CHX and the connection pipes. The steam produced from the HPZR is injected into CHX via the LCA. Steam or mixed gas passing through CHX is re-circulated into the LCA for natural circulation condition.

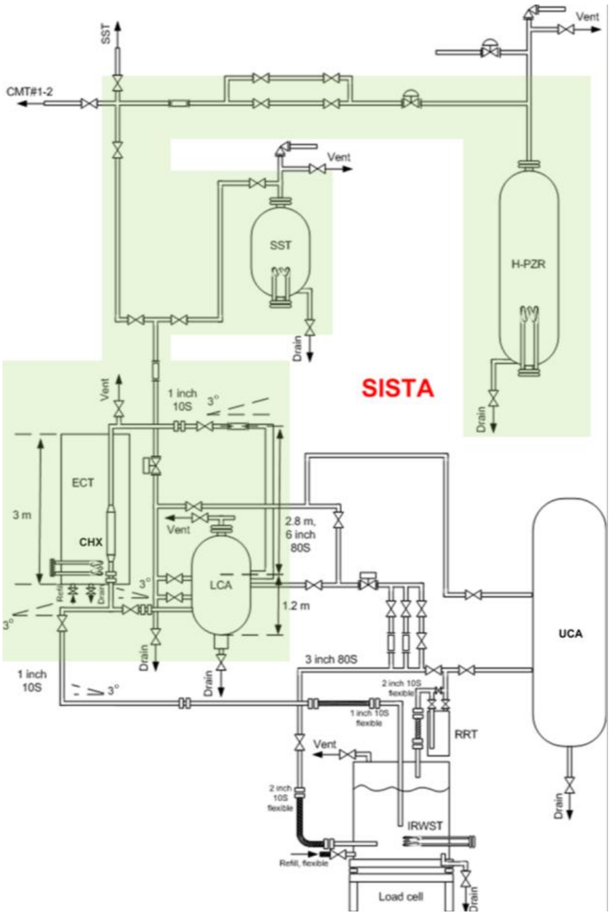

Fig. 1. Components and configuration of SISTA [2]

Fig. 2 shows the design specifications for the ECT and CHX condensation test sections. It also shows the locations of the four local temperature measurement points on the heat exchanger and the installed thermocouples. The CHX was fabricated with a 1 inch 80 SCH single stainless tube (33.4 mm OD, 4.55 mm thick, 24.3 mm ID) and installed vertically at a position 110 mm away from the ECT center line. The thermocouple is an ungrounded K type with a diameter of 1.6 mm.

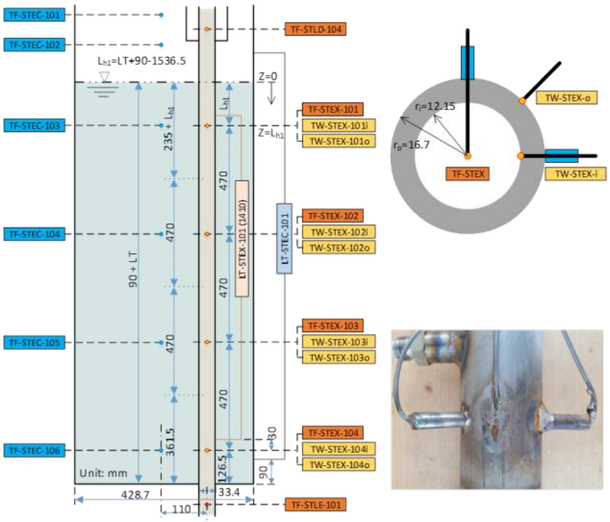

Fig. 2. ECT-CHX design specifications and local measurement method

Table I lists the instruments used in the experiments and their uncertainties of measurement. The pressure of LCA and water levels of ECT & CHX were measured by pressure transmitters. The injected steam flow rate for the natural circulation condensation experiments was measured using 0.1 inch Coriolis mass flow mater (QM-STLA-102) before the LCA. The air flow rate was measured by a thermal mass flow meter (QM-AIR-101). The temperature distribution was measured using 1.6 mm sheathed K type thermocouples with 0.4℃ accuracy.

Table I: Instruments and their uncertainties

No.	Instruments	Type	Accuracy
1	Pressure Transmitter	Rosemount 3051S1CA	0.025%
2	Level Transmitter	Rosemount 3051S1CD (LT-STEC-101)	0.025%
3	Flow Transmitters	Thermal mass flow: TLF-23 (QM-AIR-101)	1%
		Coriolis mass flow meter: Micro Motion CMFS010 (QM-STLA-102)	0.05%
4	Thermocouple	1.6ϕ sheathed K-type	0.4℃

2.2 Test conditions

Table II shows test matrix for natural circulation condensation experiments. In the experiments, main factors such as LCA pressure according to injected steam & air flow rates and temperature distribution in the CHX were investigated. The NC gas mixing conditions were simulated after maintaining quasi steady-state condition with a steam mass flow rate of about 0.148 kg/min. The air was injected two times consecutively to the each condition.

Table II: Test matrix

No.	Test condition	Steam mass flow rate (kg/min)	Injected air mass (g)	Accumulated air mass (g)
1	Pure steam	0.148	-	-
2	NC gas mixture	0.149	38.56	38.56
3		0.152	109.85	148.41

Fig. 3 shows quasi steady-state pressures of three conditions including pure steam condition. As the accumulative amount of NC gas increased, the steady-state pressure increased. The accumulative air mass of 150 g corresponds to a condition of an average air mass fraction of about 5% in LCA. It can be seen that the steady-state pressure formed is about 1.5 bar higher than that of pure steam condition.

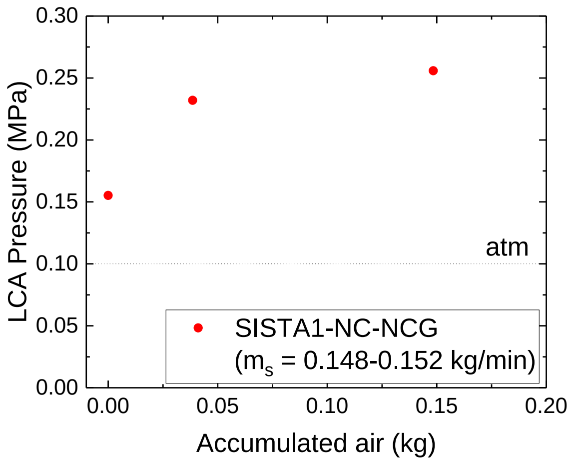

Fig. 3. Steady-state pressure according to accumulated air mass

2.3 Temperature distribution in CHX

The distribution of the air mass fraction in the system was investigated through the local temperature distribution measured along the CHX.

Fig. 4 shows the temperature distribution inside CHX. At the same time as the air injection, temperature changes occur rapidly. Position #1 (TF-STEX-101) near the CHX inlet has a value close to the saturation temperature. Temperatures of other positions (position #2 ~ #4, TF-STEX-102~104) decrease after the first air injection. It means that condensation occurs only at the CHX inlet area (position #1) and there is a heat transfer to the ECT cooling water around position #1. Afterwards, the temperature decreases in the order of position #2 ~ #4 of CHX, and in case of position #2 and #3, it increases slightly after the air injection and then decreases gradually with time. It means that air is accumulated in the heat exchanger as the condensation proceeds in the vertical pipe.

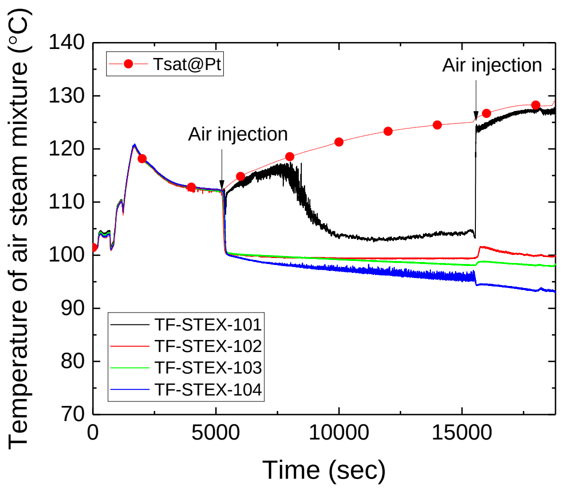

Fig. 4. Temperatures of steam-air mixture: CHX (STEX)

3. Conclusions

After 72 hours from the SBLOCA occurrence in SMART CPRSS, in order to evaluate the heat removal performance through ECT-CHX, the condensation tests under natural circulation operation were performed. Injecting a constant mass of steam into the natural circulation closed loop from LCA to CHX, the system pressure was measured for maintaining a quasi-steady condition. It was found that the pressure increased as an additional air was injected into the LCA. In the transient state after the air injection, it was found that condensation heat transfer was continuously generated at CHX position #1 (steam-air inlet). Based on the experimental results obtained in this study, the concept of long-term cooling performance of CPRSS could be verified by understanding the heat transfer characteristics of CHX in natural circulation flow path.

REFERENCES

[1] K. K. Kim, et al., SMART: The First Licensed Advanced Integral Reactor, Journal of Energy and Power Engineering, Vol. 8, p. 94-102, 2014.
[2] J. H. Yang, et al., Conceptual Validation Test of CPRSS with SISTA, Transactions of the Korean Nuclear Society Autumn Meeting, Goyang, Korea, Oct. 24-25, 2019.
[3] M. Ishii and I. Kataoka, Similarity analysis and scaling criteria for LWRs under single-phase and two-phase natural circulation, NUREG/CR-3267, ANL-83-32, 1983.