Local Reverse Heat Transfer of Condensation Heat Exchanger with Non-condensable Gas

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1. Introduction

SMART CPRSS [1] is an engineered safety feature (ESF) system that suppresses the increase of pressure and temperature in the containment when a loss of coolant accident (LOCA) occurs. It uses condensation heat exchanger, CPRSS heat exchanger (CHX), to reduce pressure and temperature of containment building. Non-condensable gas also moves into the CHX and it can interrupt condensation heat transfer. Accumulated air reduces local temperature in the CHX, it can be lower than the ultimate heat sink temperature.

In this study, local reverse heat transfer of CHX owing to the accumulated non-condensable gas (air) was investigated.

2. Experimental Facility

The SMART IRWST separate effect test apparatus (SISTA) [2] was used for condensation experiment with non-condensable gas in the CHX. Steam and non-condensable gas mixture passes through CHX and condensate returns to the tank as shown in the Fig.1. The non-condensable gas was accumulated in the CHX and it reduced partial pressure and temperature of fluid.

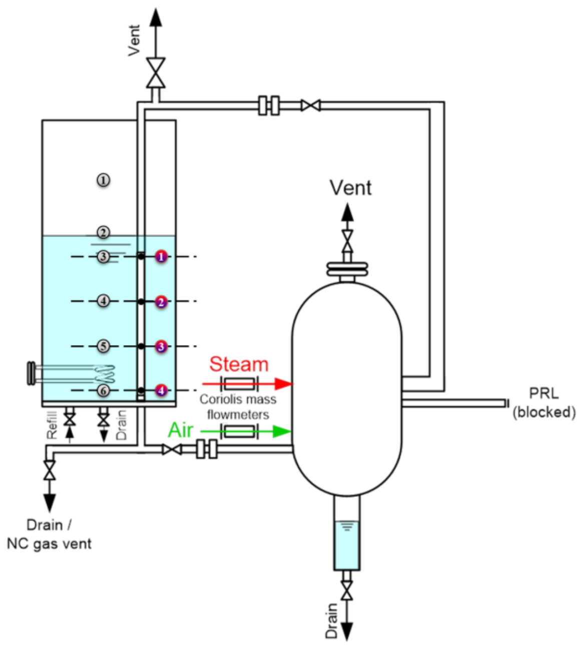


Fig. 1. Condensation experiment loop

Fig. 2 shows design specifications of condensation test sections including emergency cool-down tank (ECT) and CHX. It shows the locations of the four local temperature measurement points of the CHX and ECT. 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.

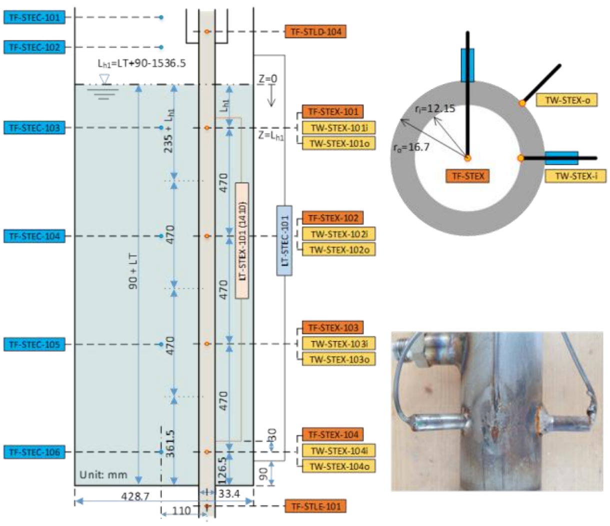


Fig. 2. ECT-CHX design specifications and installation of thermocouples [1]

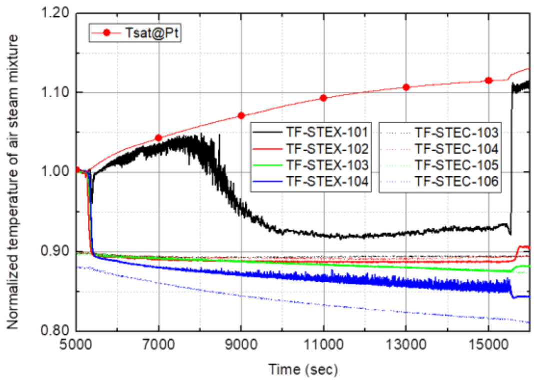
3. Experimental Conditions and Results

Table I shows test matrix for steam and air mixture condensation experiment in the heat exchanger. The air injection experiment was conducted after the boundary condition was maintained as quasi steady-state with a pure steam injection of 0.148 kg/min. And 38.56 g (2% of mass) of air was additionally injected at 5,069 seconds.

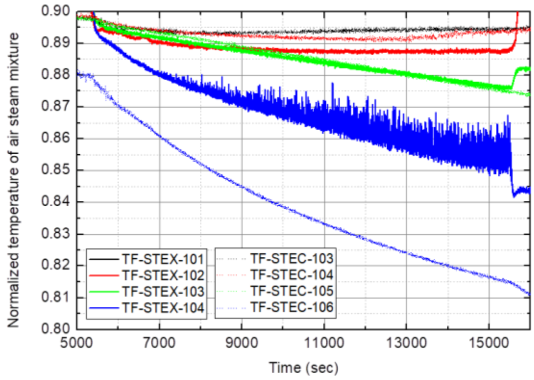
Table I: Test matrix

No.	Test condition	Steam mass flow rate (kg/min)	Injected air mass (g)	Test Time after Air Injection (s)
1	Pure steam	0.148	-	-
2	Air mixture	0.149	38.56	10,131

Fig.3 presents the fluid temperature distribution of the heat exchanger. The air was injected after steady-state operation with steam (5,069 s). When the air and steam mixture passed through the heat exchanger, the fluid temperatures measured in heat exchanger were changed. TF-STEX-01, the upper part of heat exchanger was instantaneously reduced and then increased again. After that, the difference between the saturated temperature and the measured temperature was maintained within 3℃ for more than 2,500 seconds. After about 1 hour of air injection, it decreased to a difference of 10℃ or more. Because fluid temperature of ECT (TF-STEC-03) was maintaining as 100℃ during 1 hour after air injection, the amount of heat transferred from heat exchanger to ECT was large in 2,500 seconds and it was relatively small after 2,500 seconds. In the lower part of CHX (TF-STEX-04), the fluid temperature inside heat exchanger was the lowest due to accumulated air, but the temperature of ECT (TF-STEC-06) was lower than heat exchanger, so heat transfer from heat exchanger to ECT was possible. The reason why the lower part temperature of ECT was low is because a thermal stratification was progressed inside the ECT. The temperatures in the middle of CHX (TF-STEX-02&03) show 1~2℃ of differences between the temperatures of the ECT (TF-STEC-04&05). Interestingly, heat transfer in the opposite direction from the ECT to the CHX was observed in the middle part, not in the lower part of the heat exchanger where the non-condensable gas was expected to be accumulated. In TF-STEX-02 and TF-STEC-04, the reverse temperature difference increased and the heat of ECT was transferred to the heat exchanger. However, since this difference was very small, it could be negligible compared to the amount of heat transferred from the heat exchanger to the ECT.



(a) Temperature distribution in CHX and ECT



(a) Reverse heat transfer at TF-STEX-102 and TF-STEC-104

Fig. 3. Local reverse heat transfer of CHX

4. Conclusions

The condensation experiment with non-condensable gas in the heat exchanger, CHX, was conducted. The local reverse heat transfer of CHX because of the accumulated non-condensable gas can be observed in the CHX. The heat transfer on the opposite direction was not expected in the design of heat exchanger, but it can be negligible compared to the amount of heat transferred from the heat source to the ultimate heat sink. It can be a reference for the design of the passive safety system using condensation heat exchanger with non-condensable gas.

REFERENCES

[1] J. H. Yang, et al., Conceptual Validation Tests on Condensation during Natural Circulation Using SISTA, Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea, July 9-10, 2020.

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