Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 26-27, 2017

Performance test of air to steam counter flow heat exchanger for long-term passive cooling system

Seon Jeong Huh[a], Joo Hyung Moon[b], Youngmin Bae[b], Young In Kim[b], Hee Joon Lee[a*]
[a]*School of Mechanical Engr., Kookmin University, Jeongneung-ro 77, Seongbuk-gu, Seoul, 02707, Korea*
[b]*Korea Atomic Energy Research Institute, Daedeok-daero 989-111, Yuseong-gu, Daejeon, 34057, Korea*
**Corresponding author: joellee@kookmin.ac.kr*

1. Introduction

As an accident occurs in nuclear reactor, passive cooling system is operated even if there is no supply of electric power. To maintain cooling system to work, it is needed to operate for a long time.

The concept of long-term passive cooling system for an emergency cooldown tank (ECT) was first suggested by Kim *et al.* [1], the United States patent. Kim *et al.* [2] proved the concept experimentally that long-term passive cooling system for an ECT operated successfully for 72 hours, which collected water and refilled the ECT with it. Air-cooled condensing heat exchanger in this system improved stability of operation. Kim [2] evaluated cooling capacity and average natural convective heat transfer coefficient around the vertical-type air-cooled condensing heat exchanger. In the previous study, Huh *et al.* [3] investigated local condensation heat transfer coefficient by an in-house thermal sizing program of condenser (TSCON) and compared it to existing correlation. Moreover, sensitivity was analyzed. It was found that sensitivity at air side of the heat exchanger was larger than that of condensation side. Therefore, wall temperature of the heat exchanger is needed to be measured more delicately. However, as the heat exchanger consisted of 25 tubes with half inch diameter there existed disturbance of air around the vertical tubes. Temperature could not be measured accurately because of the disturbance. Therefore, new air-cooled

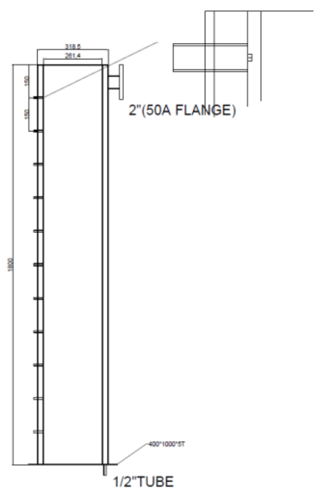


Fig. 1. Schematic diagram of air to steam counter flow heat exchanger

shell(steam) and tube(air) type heat exchanger was designed to measure the wall temperature of the heat exchanger without disturbance of air flow. Since thermocouples were installed through shell side in which steam flows very slowly, sensor wires did not interfere with air natural convection in tube side.

In this study, an experiment was conducted in a 1/2500-volume scaled-down model of the emergency cooldown tank (ECT) of the system integrated modular advanced reactor (SMART). Air to steam counter flow heat exchanger for long term passive cooling system was correspondingly designed. Moreover, performance of the new shell and tube type heat exchanger was evaluated.

2. Methods and Results

2.1 Experimental setup

Fig. 1. shows schematic diagram of the new air to steam counter flow heat exchanger. The area of heat transfer was the same with the previous heat exchanger. For the new heat exchanger, two 3mm thick SUS 304L pipes with different diameters were used. The height of the pipes were 1.8 m. Outer and inner diameter were 318.5 mm and 261.4 mm respectively. The center of both pipes was at the same location. Air flowed the inner tube part and steam flowed the outer tube part. To measure wall temperature of heat exchanger, 11 type-T thermocouples (OMEGA TMQSS-125U-6) were installed at the side of the heat exchanger. Thermocouples were located in the steam side, they were not disturbed by the air flow. It was the inner part wall temperature that thermocouples measured. Each thermocouple was spaced out 150 mm apart. Another 2 type-T thermocouples were installed to measure inlet and outlet temperature of heat exchanger. The heat exchanger was insulated with Cerakwool blanket. At the bottom, flow meter was placed. When a valve was opened, current was measured by DAQ (Yokogawa GM10). For the ECT, 1/2500-volume scaled-down model of emergency cooldown tank of system-integrated modular advanced reactor (SMART) was used.

2.2 Methods

The experiment was conducted under 1.1 kW and 1.3 kW heat loads. As steam condensed incompletely at 1.5

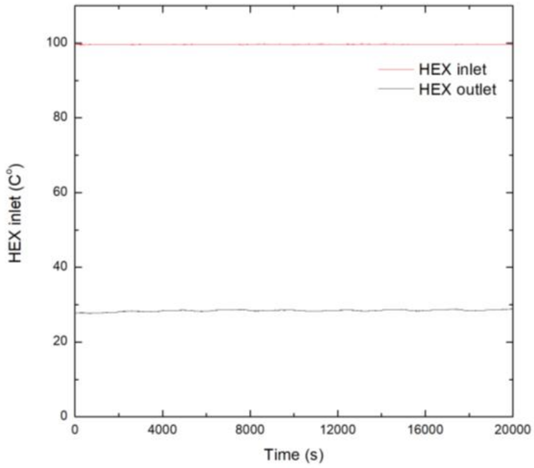


Fig. 2. Temperature of Inlet and outlet of heat exchanger at 1.1 kW heat load

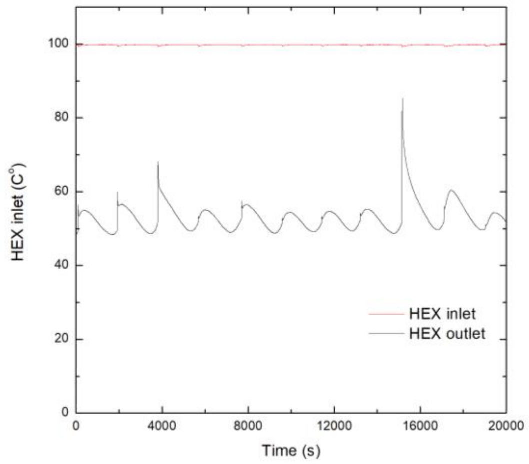


Fig. 3. Temperature of Inlet and outlet of heat exchanger at 1.3 kW heat load

kW heat load, 1.1 kW and 1.3 kW were chosen for experimental conditions. When water in the ECT boiled and reached to steady state, data was obtained.

With the obtained data of temperature, cooling capacity was evaluated as follows,

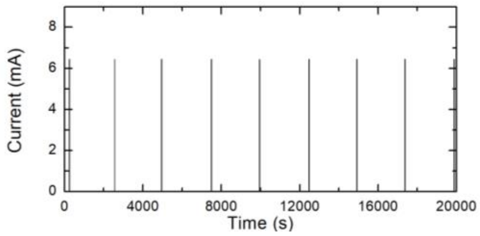
$$\dot{Q} = \dot{m}(i_{in} - i_{out}) \quad (1)$$

Where $\dot{Q}$ is cooling capacity, $\dot{m}$ is mass flow rate, i_{in} and i_{out} is enthalpy of inlet and outlet of the heat exchanger. Furthermore, heat loss was calculated from the cooling capacity.

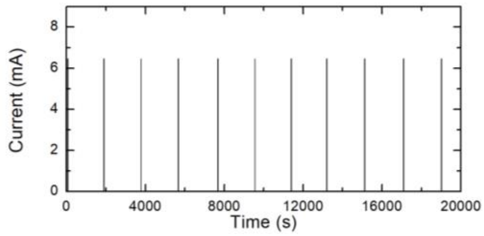
Condensing flow rate was calculated using the current interval from flow meter.

2.3 Results

Fig. 2. and Fig. 3. show the temperature of inlet and outlet of the heat exchanger at 1.1 kW and 1.3 kW of



(a) Current measured when the heat load was 1.1 kW



(b) Current measured when the heat load was 1.3 kW

Fig. 4. Current measured when valve of flow meter opened.

Table I: Cooling capacity and mass flow rate at 1.1 kW and 1.3 kW heat load

Heat load (kW)	Cooling capacity (kW)	Mass flow rate (g/s)
1.1	0.71	0.2754
1.3	0.89	0.3572

heat load. The average temperature of the outlet at 1.1 kW and 1.3 kW were 27.2 ℃ and 45.6 ℃ respectively.

Fig. 4 shows current measured when valve of flow meter was opened. The larger the heat load was, the more frequent the valve was opened.

As shown in Table I, cooling capacity of heat exchanger was found to be 0.71 kW and 0.89 kW at 1.1 kW and 1.3 kW heat load respectively. Mass flow rate was 0.2754 g/s and 0.3572 g/s.

3. Conclusions

In this study, performance of air to steam counter flow heat exchanger was evaluated. Cooling capacity of the heat exchanger was 0.71 kW and 0.89 kW, when the heat load was 1.1 kW and 1.3 kW. Both were larger than those of heat exchanger used for previous work [2] and [3]. It was found that heat loss of each was 35% and 32%. Mass flow rate was obtained as 0.2754 g/s at the heat load of 1.1 kW and 0.3572 g/s at 1.3 kW.

Local wall temperature was measured successfully. Thus, the data was used to calculate local condensation heat transfer coefficient.

REFERENCES

[1] Y. -I. Kim, K. K. Kim, Y. Bae, J. H. Yoon, J. J. Ha, W. J. Lee, and T. Y. Kim, Cooling system of emergency cooling

tank and nuclear power plant having the same, Korea Patent App, No. 10-2013-0052051, 2013.

[2] M. J. Kim, J. H. Moon, Y. Bae, Y. I. Kim and H. J. Lee, Feasibility Test of the Concept of Long-term Passive Cooling System of Emergency Cooldown Tank, Annals of Nuclear Energy, Vol. 80, p. 403-408, 2015.

[3] S. J. Huh, J. H. Moon, Y. Bae, Y. I. Kim and H. J. Lee, Condensation heat transfer coefficient of air-cooled condensing heat exchanger of emergency cooldown tank in long-term passive cooling system, Proceedings of ICAPP 2017

[4] S. J. Kim, H. C. No, Turbulent film condensation of high pressure steam in a vertical tube, International Journal of Heat and Mass Transfer, Vol. 43, p. 4031-4042, 2000