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Experimental Investigation of Heat Loss on a Heat Exchanger in a Sodium Test Facility

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1. Introduction

To validate the design of the safety-grade decay heat removal system (DHRS) in a PGSFR (Prototype Gen-IV Sodium-cooled Fast Reactor), two kinds of sodium-to-air heat exchangers have been employed in the system as an ultimate heat sink [1]. One is a natural-draft sodium-to-air heat exchanger (AHX) with helically-coiled sodium tubes, and the other is a forced-draft sodium-to-air heat exchanger (FHX) with finned-tubes with a straight-type arrangement. For the verification of the heat transfer performance in various operating conditions, SELFA (Sodium thermal-hydraulic Experiment Loop for Finned-tube Sodium-to-Air heat exchanger) was designed and constructed to examine the heat transfer and flow characteristics of FHX in PGSFR [2].

Test components using high temperature liquid sodium, such as a model FHX (M-FHX) in SELFA, is likely to have a significant effect on the temperature results due to heat loss. Heat loss quantities on a component can be estimated by both theoretical and experimental approaches [3]. The heat loss of the sodium in the heat exchanger is assumed to be caused only by the air flow from the blower, but in fact, the heat loss is also occurred through the structure of the SELFA. This study was performed to observe the characteristics of heat loss occurring through the outer wall of the SELFA and to research its characteristics. This work will be very important to improve the accuracy and the responsibility of experimental results from FHX in SELFA.

2. Methods and Results

2.1 Configuration of M-FHX

The configuration of SELFA and the shape of M-FHX used in this study is shown in Fig. 1. The SELFA facility is using liquid sodium as a working fluid, and the dimension of M-FHX is about 3 m (width) x 2 m (depth) x 3 m (height). At the center of the M-FHX, there is a support structure that supports the heat transfer tube and induces the flow of air. The gap between the outer wall of the heat exchanger and the support for bending parts and chambers is tightly filled with a thermal insulator.

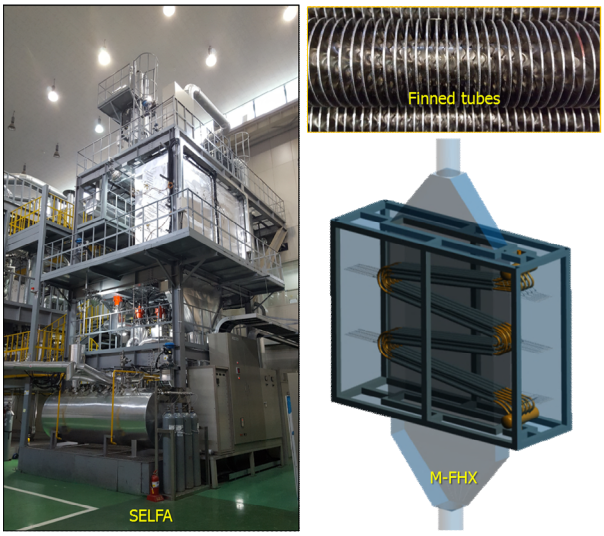

Fig. 1. Configuration of SELFA and M-FHX.

In order to measure the heat loss occurring through the SELFA structure, the inlet and outlet dampers of the air flow path were closed to block the intake air flow. Then, the amount of heat loss through the structure at the thermal equilibrium state was measured.

2.2 Experimental Procedure

The experiment was carried out under almost steady state conditions judged based on the minimization of temperature changes for 10 minutes. The degree of change of temperature for 10 minutes to determine steady state was limited to within ± 0.5 ℃ for sodium temperature and 2 ± 0.005 kg/s for sodium flow.

The heat loss of the sodium in the heat exchanger was measured by using the sodium temperature change at the inlet and outlet of the heat exchanger, the specific heat of sodium, and the flow rate of sodium. The temperature of the inlet was the average temperature of the sodium upper chamber and the temperature of the outlet was the average temperature of the sodium lower chamber. The specific heat of sodium was used to approximate each temperature, and the flow rate of sodium was determined by using an average flow rate during 10 minutes.

2.3 Experiment result

The heat loss of sodium can be calculated by the Eq. (1), and the experimental conditions and results are summarized in the Table I.

$$Q = cm\Delta T \quad (1)$$

Table I. Experimental conditions and results.

Inlet Temp. (℃)	Outlet Temp. (℃)	Structure ΔT (℃)	Heat Loss (W)
200.06	197.84	0.36	5984.15
199.88	197.85	0.23	5232.19
250.01	246.91	2.01	10064.60
249.87	247.24	-0.71	4554.62
299.89	295.48	3.00	12630.54
299.79	296.89	-1.63	8802.23
349.81	344.18	3.80	12907.86
349.93	345.00	0.98	12277.22
350.01	344.97	0.93	13221.80
349.93	345.11	0.80	12704.63

2.4 Effect of Structure Temperature Differences

Even though the heat exchanger inlet / outlet temperatures of sodium are similar, it can be seen that there is a large difference in heat loss depending on how close the experiment is to the steady state. It is difficult to theoretically verify the heat loss because the heat lost to sodium is released to the final heat sink cause atmosphere and the calculation variables vary. Therefore, we calculated the heat loss which reduces the uncertainty of each physical quantity and the temperature variation of the SELFA structure, which is considered to reflect various variables, to zero.

The heat loss behavior is assumed to be linearly proportional to temperature and the heat loss is estimated using a least square straight line.

For simple modification, we supposed that the least-squares linear equation can be applied as Eq. (2) – (4).

$$\mathrm{f(T) = aT + b} \quad (2)$$

$$\mathrm{a} = \frac{\sum_{i=1}^{n}(H_i - \bar{H})(T_i - \bar{T})}{\sum_{i=1}^{n}(T_i - \bar{T})^2} \quad (3)$$

$$\mathrm{b} = \bar{H} - a\bar{T} \quad (4)$$

, where H and T are the heat loss and the temperature variation of the SELFA structure, respectively. The value when f(0) is the heat loss when there is no temperature change of the SELFA structure. Table II represents the corrected heat loss values without the estimated effect of structure temperature differences, and Fig. 2 shows the comparison between the corrected values and experimental raw results. Experimental results are shown empty triangle, modified values are shown by square, and modified value trend lines are added.

Table II. Modified heat loss results.

Test Temp (℃)	Heat Loss (W)
200	3883.09
250	5992.89
300	10145.86
350	12685.58

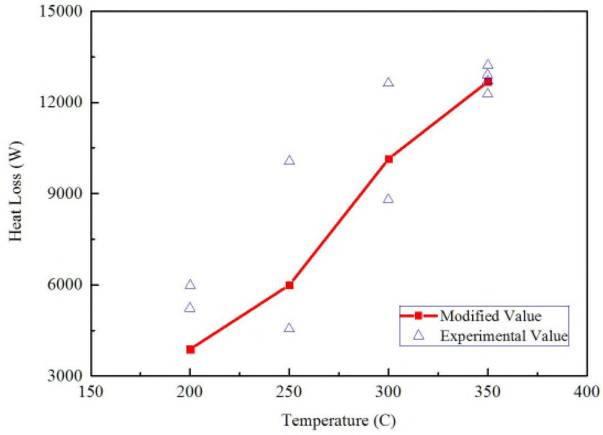

Fig. 2. Comparison between the modified and experimental raw values.

3. Conclusions

The heat loss characteristics of M-FHX in the SELFA facility were investigated by experiments. The temperature conditions were varied from about 200°C to about 350°C. Because the measured heat loss quantities of M-FHX were inadequate to show the heat loss characteristics as they were, we additionally considered the structure temperature difference effect. The modified results represent pretty good agreements, and this result can be applied to obtain more accurate analysis for heat losses on a high temperature component such as M-FHX.

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REFERENCES

[1] J. YOO, Status of Prototype Gen-IV Sodium Cooled Fast Reactor and its Perspective, Transactions of the Korean Nuclear Society Autumn Meeting, Gyeongju, Korea, October 29-30, 2015.

[2] Jae-Hyuk EOH et al., Thermal Sizing of a forced draft sodium-to-air heat exchanger and its operation strategy in KALIMER, Transactions of the Korean

Nuclear Society Autumn Meeting, Pyungchang, Korea, Oct. 30-31, 2008.
[3] S. Cho et al., Heat Loss Evaluation of the ATLAS Facility, Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea, May 22, 2009.