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Experimental Evaluation of Heat Loss Characteristics in Thermally-insulated Piping System of a Sodium Test Facility

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1. Introduction

In the process of developing a new nuclear system, experimental verification using a scaled-down thermal-hydraulics facility with similarity to the prototype is often required. However, heat losses in a scaled facility is generally overestimated rather than the prototype due to the increase in volume to surface area ratio, which is one of the critical factors that distort the actual thermal-hydraulic characteristics expected in the prototype. So, if we can understand exactly what the heat loss characteristics in the thermal-hydraulic facilities for experiments will be and compensate for it, the reliability of the experimental results produced by the facility can be greatly improved [1].

The KAERI (Korea Atomic Energy Research Institute) has been developing the PGSFR (Prototype Gen-IV Sodium-cooled Fast Reactor) as the next generation nuclear power plant, and is carrying out STELLA (Sodium Test Loop for Safety Simulation and Assessment), a demonstration program to support this. Especially, in the case of STELLA-2, a large-scale sodium thermal-hydraulic integral effect test facility, which is currently in progress to design, it is planned to experimentally demonstrate the sodium thermal hydraulic characteristics and safety in various accident cases in future. The heat loss on the test facility for this kind of the integral effect test needs to be examined more specifically [1].

This paper presents the experimental results of heat losses of thermally-insulated piping system of a sodium test facility, which is the sodium test facility called SELFA (Sodium thermal-hydraulic Experiment Loop for Finned-tube sodium-to-Air heat exchanger) [2].

2. Methods and Results

2.1 Details of the pipe system

The thermally-insulated sodium pipes of the SELFA facility consists of a 100 mm thick insulation (Cerak wool) on the outside of the stainless steel pipe (STS304L) with an outer diameter (OD) of 60.5 mm and a thickness of 3.5 mm. All exposed parts except sensor outlets such as thermocouples are covered with the same thickness of insulation and the body part of the sodium valve is also insulated in same manner as shown in Fig. 1. The schematic drawing of Fig. 1 shows the cross section and profile of the pipe.

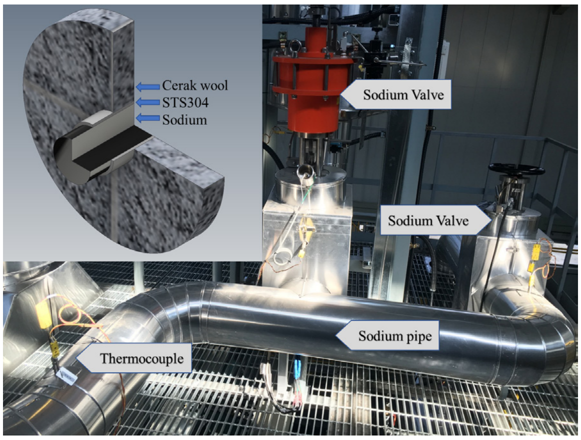

Fig. 1. The picture of the pipe configurations and the implemented image for the schematic drawing including the cross section information of the pipe.

2.2 Experimental Procedure and Results

The experiment for heat loss of sodium pipes was conducted by a differential approach [1, 3]. In order to prevent additional heat losses from the liquid sodium to the solid structures as sodium valves, these surrounding components should sufficiently heated up to the almost same temperature with sodium. For this, a sufficient waiting time before starting the temperature measurement due to heat loss was allowed at 350˚C for 3 hours. When the temperature of the SELFA's major part was monitored and it was judged that the device had reached a thermal steady state (i.e., without any temperature changes), an electromagnetic pump (EMP) was turned off and all sodium valves were closed to minimize the internal natural convective flow of sodium. Then, we got the temperature information of liquid sodium inside pipes at every seconds. The experiment was continued before the time when the minimum temperature of the temperature sensor reached 160˚C in order to prevent solidification of sodium inside the pipes.

Fig. 2 represents the temperature measurement positions and groups for analyses of the measured results considering characteristics of installation location of thermocouples. Group 1 contains the thermocouples that are relatively far from the components that can affect as a heat sink or a heat source and is likely to exhibit heat loss characteristics on the pipe itself. Group 2 is relatively close to the large volume of heated sodium, such as a loop heater and an expansion tank. Last one is group 3 which is installed adjacent to non-insulated components such as an EMF or an EMP, and it is expected to have much larger heat loss than those of other groups.

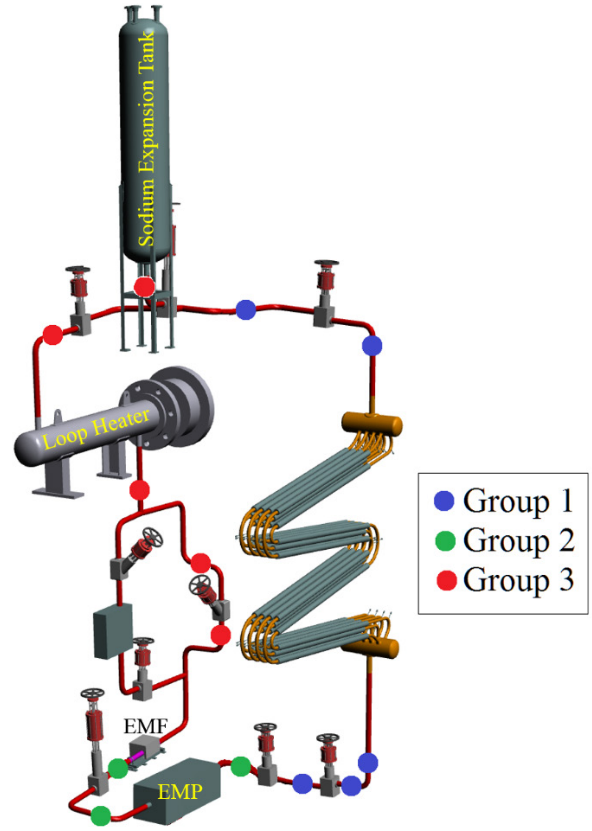

Fig. 2. Profile of SELFA's piping and temperature measurement position

Fig. 3 shows the temperature changes of the representative thermocouples in each groups for about 150 min. The temperature of CL-06 belonging to Group 2 can be confirmed to have a relatively large slope as compared with a case where the slope of CL-02 representing Group 1 is decreased. Also, the HL-01 in Group 3 shows that the temperature decrease is minimized during the test as expected. The outside temperature of the pipe was maintained as the constant value of about 4.5 ˚C.

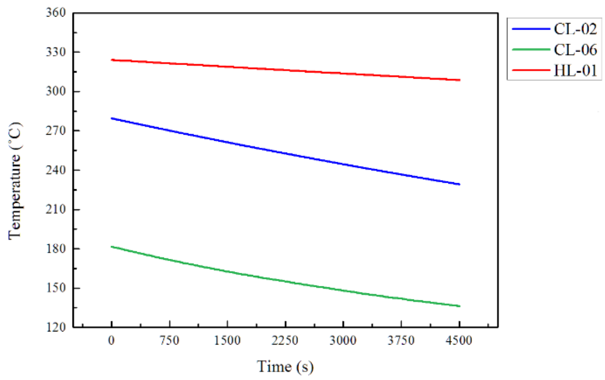

Fig. 3. Sodium temperature over time of the representative thermocouples in each groups.

2.3 Heat loss calculation results

Using the empirical correlation was used to calculate a heat loss on the pipe with same configuration as shown in Fig. 1 and the following equations [4]. The thermal properties such as Thermal conductivities and heat capacities of each materials at each temperature were linearly interpolated at known values.

$$q = \bar{h} A_s (T_s - T_\infty)$$

$$\bar{h} = \frac{k}{D} \overline{Nu_D}$$

$$\overline{Nu_D} = \left\{ 0.60 + \frac{0.387 Ra_D{}^{1/6}}{\left[1 + (0.559/Pr)^{9/16}\right]^{8/27}} \right\}^2, \; Ra_D \leq 10^{12}$$

In the experimental heat loss calculation, the measured sodium temperatures were considered as an average temperature of liquid sodium inside the pipe. The overall measured temperature range was from 130 ˚C to 330 ˚C. The measured temperatures were treated by dividing the temperature intervals in every 10 ˚C for the calculations, and the physical quantity of sodium is taken as the average value of the interval temperature.

The theoretical heat loss Q at each temperature interval and the heat loss at that temperature interval observed in the experiment are calculated and shown in Fig. 4.

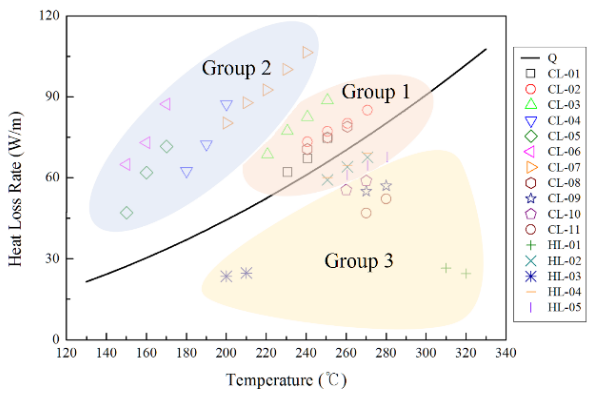

Fig. 4. The heat loss calculation results compared with the theoretical result.

In the case of Group 1, theoretical and experimentally obtained heat losses are comparable as expected, but in the case of Group 2, the experimental heat losses are much larger than the theoretical values. This appears to be a relatively large loss of heat due to the proximity of components not covered by the insulation, such as EMP and EMF, which exhibits greater than over 30% larger heat loss when compared to those in Group 1. And the heat losses of Group 3 show less than those of Group 1, because they can receive additional heat from the large amount of hot sodium inside the container with large volume, such as the expansion tank and a loop heater. As a result, the theoretically and experimentally obtained heat flux on the pipes was very reasonable with the preliminary expectations.

3. Conclusions

The heat loss on the pipe with thermal insulation were determined by the experiment through a differential approach. The obtained results represent the reasonable heat losses of each classified groups with the preliminary expectation. For this work, more accurate predictions of the heat loss in a thermally-insulated sodium pipe will be able, and it will be used to calculate the total heat loss of the whole facility by synthesizing the heat loss in other components in the future. This can be expected to more accurately predict the transient thermal-hydraulic characteristics of the facility and improve its similarity with the prototype.

ACKNOWLEDGMENTS

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