Experimental Study on Natural Convection Air Flow Characteristics in a Finned-tube type Sodium-to-Air Heat Exchanger System

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1. Introduction

A PGSFR (Prototype Gen-IV Sodium-cooled Fast Reactor) under development as the fourth generation nuclear power plants in KAERI (Korea Atomic Energy Research Institute) has a DHRS (Decay Heat Removal Systems) to remove decay heat from the reactor core in case of an accident such as a failure of the relevant equipment or an interruption of power supply [1]. This system evacuates heat from the reactor core to the environmental air in case of the failure of the steam generator or station black out. A PGSFR adopted two different kinds of sodium-to-air heat exchangers in a DHRS: one is a finned-tube type sodium-to-air heat exchanger called the FHX (Forced-draft sodium-to-air Heat eXchanger) in an ADHRS (Active Decay Heat Removal System) and another is helical-tube type sodium-to-air heat exchanger called the AHX (natural-draft sodium-to-Air Heat eXchanger) in a PDHRS (Passive Decay Heat Removal System) [2]. Each type of heat exchanger should be tested experimentally to verify the heat transfer performance and thermal-hydraulic behaviors.

KAERI constructed SELFA (Sodium thermal-hydraulic Experiment Loop for Finned-tube Sodium-to-Air heat exchanger), which includes the M-FHX (Model Finned-tube type sodium-to air Heat eXhanger) having reduced power scale and unit length scale with the reference the FHX. Although the FHX is an active component, it can be also used in passive conditions to prepare an addition safety measure for accidents. Therefore, experimental evaluations of natural convection characteristics of the FHX is essential [3,4].

In this paper, to study natural convection characteristics of the FHX, the test was performed using the M-FHX in SELFA and the experimental results were also evaluated by comparison with the calculation results of one-dimensional safety analysis code.

2. Test and Calculation Methods

2.1 The SELFA facility

Sodium loop of the SELFA is a closed loop as shown in Fig.1. Liquid sodium flowrate is controlled by an EMP (electromagnetic pump), and it is measured through an electromagnetic flow meter. Sodium is heated up in a loop heater before the upper sodium chamber of the M-FHX, and then hot sodium is cooled down by shell-side air in the M-FHX. The dampers installed at both inlet and outlet of air flow path can control air flow. Fig. 1 represents the schematic diagram of the SELFA facility.

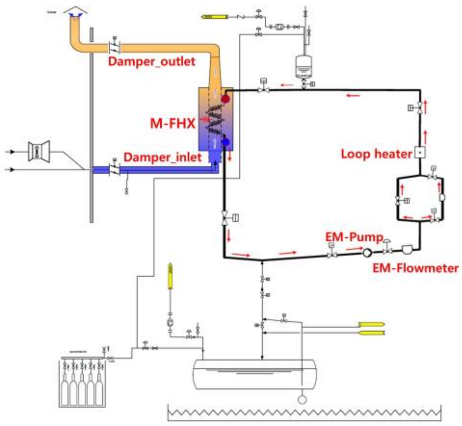

Fig. 1 The schematic diagram of the SELFA facility

2.2 M-FHX

The M-FHX is a shell & tube type heat exchanger and has the four-pass serpentine (M-shape) tubes with a large number of helical fins. The schematic of the M-FHX and its detailed images are shown in Fig.2.

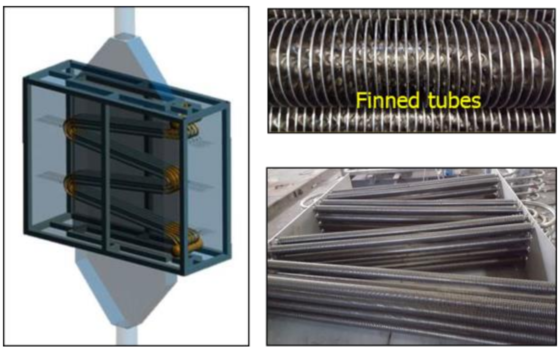

Fig. 2 Schematic of finned-tube type heat exchanger(left), and real image of finned-tube(right)

2.3 Test Procedure

Two different test conditions for this study were adopted; 300 ℃ and 200 ℃ of the inlet sodium temperatures, and 2 kg/s of sodium flow rate. The air temperature at the inlet of shell-side is based on outside temperature in the natural convection tests. Table I shows the natural convection test conditions. The air temperatures are measured values in each test.

The inlet sodium temperature was constantly controlled by the loop heater, and sodium flow rate was also constantly kept through the EMP. Once the damper was opened, then natural convective air flow in the shell-side was created. The temperature and flow rate were measured at every seconds in both sides (i.e., both sodium and air) of the M-FHX.

Table I: Test conditions of natural convection tests

Case	Sodium condition		Air condition
	Temp (℃)	Flow rate (kg/s)	Temp (℃)
1	300	2	1.17
2	200	2	11.12

2.4 Nodalization for 1-D computational analysis

MARS-LMR is a one-dimensional safety analysis code to evaluate the safety of a PGSFR in various accident scenarios. This code simplifies the complex structure of a nuclear system to one-dimensional model and calculates the system one-dimensionally. Using this code, we analyzed thermal-hydraulic characteristics of the M-FHX with the same boundary conditions of the natural convection tests. For the analysis, the M-FHX was one-dimensionally modeled as shown in Fig. 3. The tube side of the M-FHX consists of 23 nodes from the upper chamber to the lower chamber, and sodium was allowed to constant flow rate. Also the heat transfer model structure is implemented so that the heat transfer occurs only in the finned-tube area (i.e., red parts in Fig. 3).

The shell side was divided into four sections to simulate a cross flow in the heat exchanger, and each section has 17 nodes. Fig. 3 is a node diagram of the M-FHX on MARS-LMR.

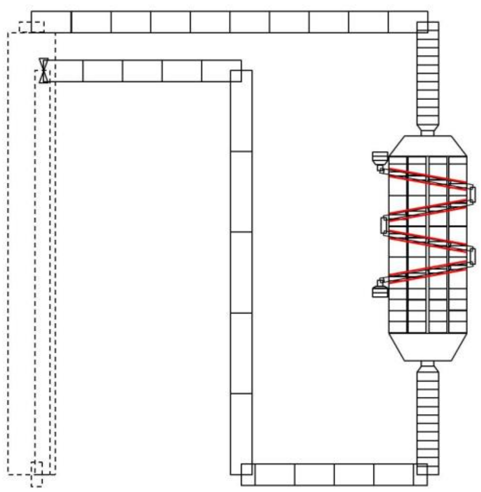

Fig. 3 Node diagram of M-FHX on MARS-LMR

3. Test and Calculation Results

The temperature and flow rate of both sides were compared with the calculation results of MARS-LMR. The inlet sodium temperature and sodium flow rate were kept constant levels in all the experiments and analysis. The outlet temperatures of sodium and air were changed in several minutes after the damper was opened, and then measured values of temperatures and flow rates were relatively kept constantly without big changes. We considered this period as a steady state.

Fig. 4 shows sodium temperatures of the test and the analysis in the Case 1 condition. In experimental results, the inlet sodium temperature was oscillated within a temperature variation of about ± 2~3 ℃ due to the automatic power feedback control of the loop heater. The outlet sodium temperature of Case 1 was 267.25 ℃, and it is 30.79 ℃ dropped from the inlet sodium temperature in the experiment. On the other hand, outlet sodium temperature was 280.89 ℃ and it shows 19.11 ℃ dropped from the inlet temperature in the analysis using MARS-LMR under the same condition. The inlet temperature of shell side air was 1.17 ℃ and the outlet air temperature was 266.28 ℃, there was a 265.11 ℃ temperature rise as shown in Fig. 5. In the results of MARS-LMR under the same condition, the inlet air temperature was 2.02 ℃ and the outlet air temperature was 259.97 ℃, there was a 257.95 ℃ temperature rise.

In Case 1, the developed air flow by natural convection was about 0.21 kg/s after the damper was opened. In the calculation results of MARS-LMR, the shell side flow rate was 0.19 kg/s. The shell side air flow rate of Case 1 is shown in Fig.6.

In the comparison between the experiments and computational analysis results for the case 1, the difference of the outlet sodium temperature was 13.64 ℃. In the case of shell-side air, the difference of the inlet air temperature was 0.85 ℃, and the difference of the outlet air temperature was 6.31 ℃.

The outlet sodium temperature of Case 2 was 183.57 ℃, which was 15.71 ℃ temperature rise from the inlet sodium temperature. In the calculation of results of MARS-LMR under the same condition, outlet sodium temperature was 188.54 ℃ which was 11.46 ℃ temperature rise from the inlet sodium temperature. The results of sodium temperatures of Case 2 are shown in Fig. 7. In Case 2, the inlet temperature of air was 11.12 ℃ and the outlet temperature of air was 181.87 ℃, there was a temperature rise of 170.75 ℃. In the results using MARS-LMR under the same condition, the inlet air temperature was 2.02 ℃ and the outlet air temperature was 172.92 ℃, which represented 170.92 ℃ temperature rise. The shell side air temperatures of Case 2 are shown in Fig.8.

In Case 2, the developed air flow rate was 0.16 kg/s after the damper was opened. In the results using MARS-LMR, the shell side air flow rate was 0.17 kg/s. The air flow rates of Case 2 are shown in Fig.9.

In the case 2, we also compared our experimental results with the calculation results by MARS-LMR. As a result, the difference of the outlet sodium temperature, those of the inlet air temperature, and those of the outlet air temperature was 4.97 ℃, 9.1 ℃, and 8.95 ℃, respectively.

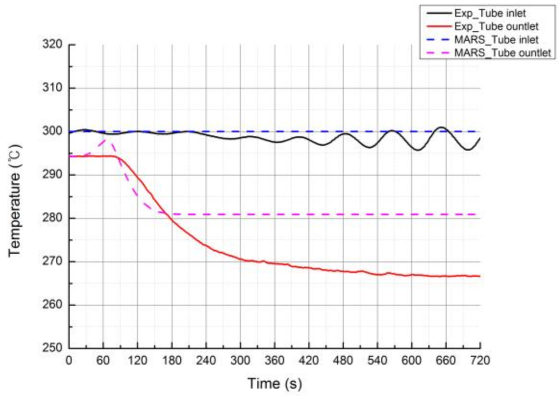

Fig. 4 The tube side sodium temperature of Case 1

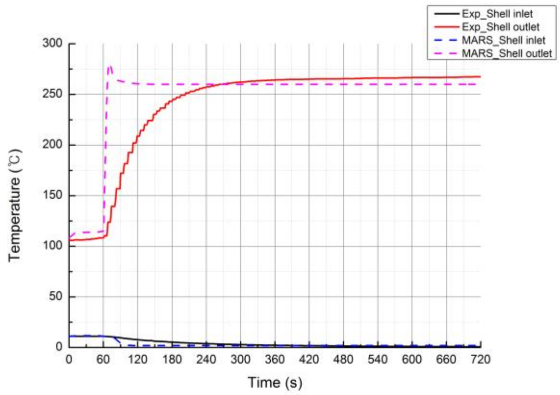

Fig. 5 The shell side air temperature of Case 1

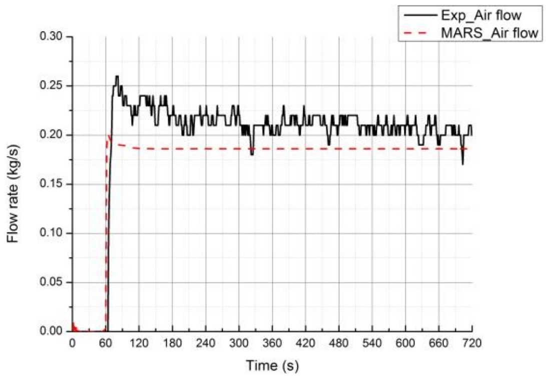

Fig. 6 The shell side air flow rate of Case 1

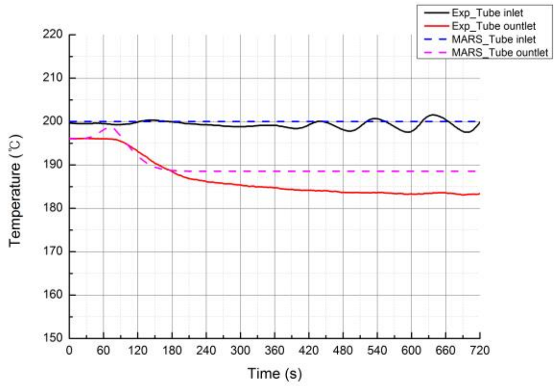

Fig. 7 The tube side sodium temperature of Case 2

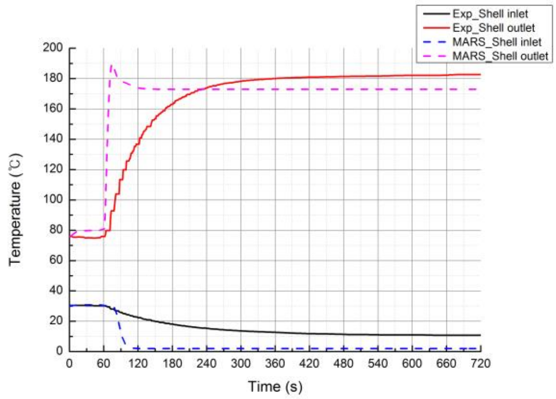

Fig. 8 The shell side air temperature of Case 2

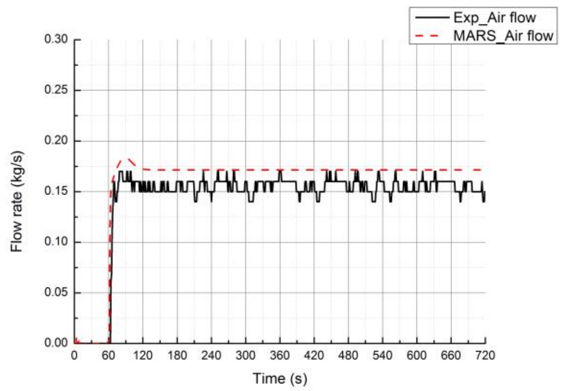

Fig. 9 The shell side air flow rate of Case 2

The heat transfer rates and comparison results of each case are shown in Table II. Heat transfer rate of the analysis using MARS-LMR was less than those of tests, because we didn't consider any kind of heat loss in the analysis.

Table II: Heat transfer rates including comparison results between experiments and analyses

	Tube side	Shell side
Case 1_Exp Q (W)	69681.03	57312.84
Case 1_MARS Q (W)	48889.97	48889.93
Ratio (%)	+29.84	+14.7
Case 2_Exp Q (W)	33235.35	27308.42
Case 2_MARS Q (W)	29672.00	29672.00
Ratio (%)	+10.72	+8.66

3. Conclusions

To study natural convection characteristics of the FHX, we performed the natural convection test using the SELFA facility, and the results were compared with the results of one-dimensional calculations. In the comparison between the experiments and computational analysis results, the maximum difference of heat transfer rates was below 30%. The more detailed analyses will be carried out in the further study.

ACKNOWLEDGMENTS

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