Performance Tests on a Forced-Draft Sodium-to-Air Heat Exchanger

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1. Introduction

A separate effect test facility called SELFA (Sodium thermal-hydraulic Experiment Loop for Finned-tube sodium-to-Air heat exchanger), one of the requisite sodium thermal-hydraulic test facilities within the framework of the STELLA (Sodium Test Loop for Safety Simulation and Assessment) program, using liquid sodium and air as operating fluids, has been developed [1–4]. Using this dedicated sodium test facility, which includes a model heat exchanger (M-FHX) designed for performance demonstration of an FHX (Forced-draft sodium-to-air Heat eXchanger) in a PGSFR, heat transfer performance tests and their uncertainty analyses have been conducted.

In this study, we report the heat exchanger performance test results on the M-FHX at various test conditions. The obtained results are then used for their heat transfer performance evaluation with analyzed error information.

2. Methods and Results

2.1 Test Procedure

The main test loop of the SELFA facility consists of an M-FHX, an electromagnetic pump (EMP), an electric loop heater, flow meters, sodium valves, an expansion tank, and a sodium storage tank, as shown in Fig. 1. The sodium storage tank contains about 1.4 tons of sodium, and ~700 kg of sodium may be used during operation. A loop heater and an electromagnetic pump allow the temperature and flow rate of the liquid sodium to be controlled. Figure 1 shows a schematic of the flow paths and heat transfer concept in the SELFA facility.

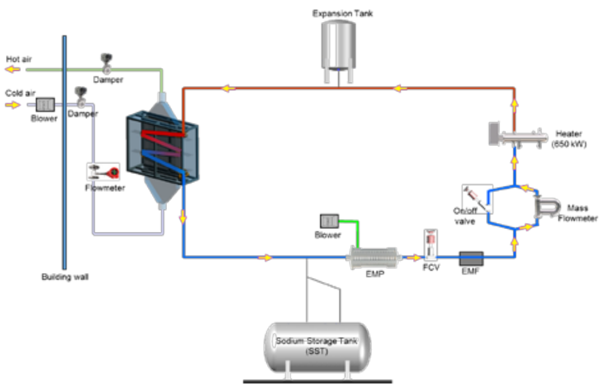

Fig. 1. Schematic of the SELFA facility, flow paths, and heat transfer information

After charging the sodium, the sodium continued to circulate until the target temperature condition was reached. If necessary, the air side flow rate was also adjusted appropriately. As a result, the sodium flow rate, sodium inlet temperature, and air flow rate were maintained during the steady-state test. Table I and Fig. 2 represent the criteria for the steady-state condition for measurements and instrumentation on the M-FHX, respectively. The measured values were the average values under a steady-state condition for 10 min, as shown in Fig. 3.

Table I: Criteria of the steady-state conditions

	Measuring Location	Tag name	Steady-state cond. for measurements
Temp.	Tube-side Inlet	TF-UC-01/02/03	(Avg. ± 1%) for over 5 min
	Tube-side Outlet	TF-CL-01/02/03	(Avg. ± 1%) for over 5 min
	Shell-side Inlet	TF-SH-01, TW-OW-01/02	(Avg. ± 1%) or (Avg. ± 1 ℃) for over 5 min
	Shell-side Outlet	TF-SH-02, TW-OW-03/04	(Avg. ± 1%) or (Avg. ± 1 ℃) for over 5 min
Flow rate	Sodium	QV-MF-01 or QM-CAL-01	(Avg. ± 1%) or (Avg. ± 1 kg/s) for over 5 min
	Air	QM-SH-01	(Avg. ± 1%) or (Avg. ± 1 kg/s) for over 5 min

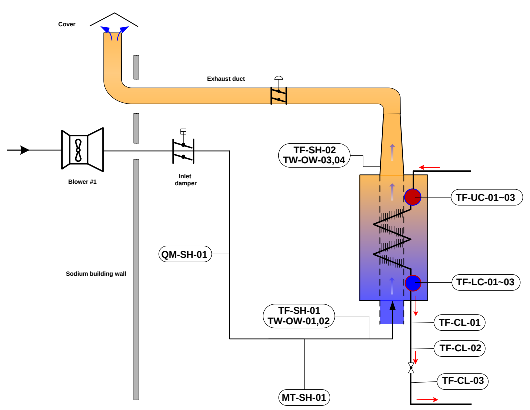

Fig. 2. Instrumentation on the M-FHX for the performance tests

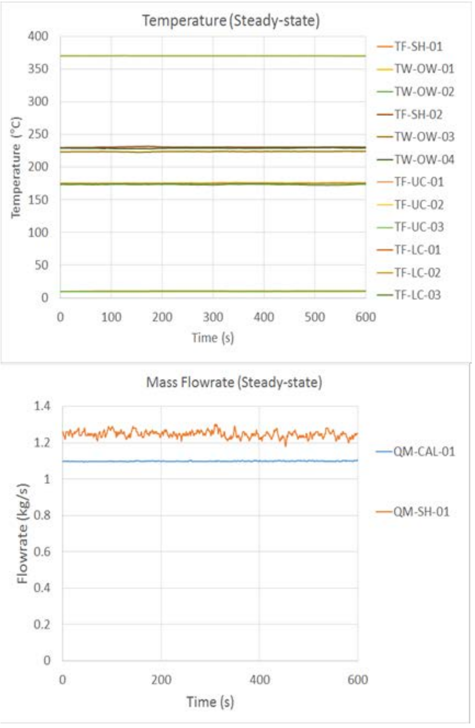

Fig. 3. Example of measured trends of temperatures and flow rates during the steady-state test

2.2 Uncertainty Analysis

For the case of the sodium temperature measurements, we defined error components as follows. Notation 'B' means bias error components, and 'P' means precision error components. The bias error components are related to the measurement system, and B_{ST1} and B_{ST2} were estimated to be ±1.5 ℃ from calibration documents, ±1.0 ℃ by additional signal transmission tests, respectively. B_{ST3} was obtained using the well-known Student's t-distribution table, statistically. B_{ST4} was conservatively defined as ±0.5 ℃ by separately conducted experiments, and B_{ST5} was considered as minus error after the heat loss tests. The precision error can be quantified using a statistical approach. P_{ST1} was calculated by taking the conservative degrees of freedom from the measured values obtained over 5 minutes, and P_{ST2} was deduced from four separate experiments performed on different dates.

- ✓ B_{ST1}: *Calibration uncertainty*
- ✓ B_{ST2}: *Data acquisition uncertainty*
- ✓ B_{ST3}: *Spatial uncertainty*
- ✓ B_{ST4}: *Installation uncertainty*
- ✓ B_{ST5}: *Uncertainty due to heat loss*
- ✓ P_{ST1}: *Random uncertainty*
- ✓ P_{ST2}: *Environmental uncertainty*

For the case of the air temperature measurements, we defined error components as follows. B_{AT1} and B_{AT2} were considered to be the same value as the sodium temperature cases. B_{AT3} was also obtained in the same manner as the previous case, using a statistical approach and Student's t-distribution. P_{AT1} and P_{AT2} were calculated in the same way as before.

- ✓ B_{AT1}: *Calibration uncertainty*
- ✓ B_{AT2}: *Data acquisition uncertainty*
- ✓ B_{AT3}: *Spatial uncertainty*
- ✓ P_{AT1}: *Random uncertainty*
- ✓ P_{AT2}: *Environmental uncertainty*

For the case of the sodium flow rate measurements, we used both a Coriolis flow meter and an electromagnetic flow meter. Defined error components are as follows. B_{SF1} and B_{SF2} were considered to be ±0.0125 kg/s and ±0.001 kg/s, respectively. B_{SF3} is based on the transfer error from the current signal in 4mA ~ 20mA to the physical flow meter, the value being considered as ±0.0005 kg/s. P_{SF1} and P_{SF2} were quantified by statistical approaches.

- ✓ B_{SF1}: *Calibration uncertainty*
- ✓ B_{SF2}: *Data transfer uncertainty*
- ✓ B_{SF3}: *Data record uncertainty*
- ✓ P_{SF1}: *Random uncertainty*
- ✓ P_{SF2}: *Environmental uncertainty*

For the case of the air flow rate measurements, we also considered installation uncertainty. The other measurements were calculated with the same procedure.

- ✓ B_{AF1}: *Calibration uncertainty*
- ✓ B_{AF2}: *Data transfer uncertainty*
- ✓ B_{AF3}: *Data record uncertainty*
- ✓ B_{AF4}: *Installation uncertainty*
- ✓ P_{AF1}: *Random uncertainty*
- ✓ P_{AF2}: *Environmental uncertainty*

In addition, we considered the measurement errors of air humidity. As a result, 3.5%R.H. for the bias error and 0.112%R.H. for the precision error were used in the uncertainty analyses. Table II and Table III summarize the relative influences of each error component.

Table II: Bias (system) error component influence

Description	Influence
Calibration error for used instruments	Moderate
Data acquisition error on transmitting	Small
Data recording error on HMI program	Small
Error due to manufacturing tolerance	Moderate
Error due to spatial variation	Large

Table III: Precision (random) error component influence

Description	Influence
Random error of measured values	Moderate

Random error for repeated tests on different days	Moderate

2.3 Performance Test Results

A total of 16 performance tests were conducted at the first stage, as shown in Fig. 4. According to our calculated values, the test range in the heat transfer rate was 37–365 kW. Most of the results are in very good agreement in terms of heat transfer between sodium and air. However, some results conducted at relatively low heat transfer rate and high sodium temperature show a larger discrepancy due to the heat loss effect of sodium. Total uncertainty in the heat transfer rate is less than 30 kW when it is considered very conservatively.

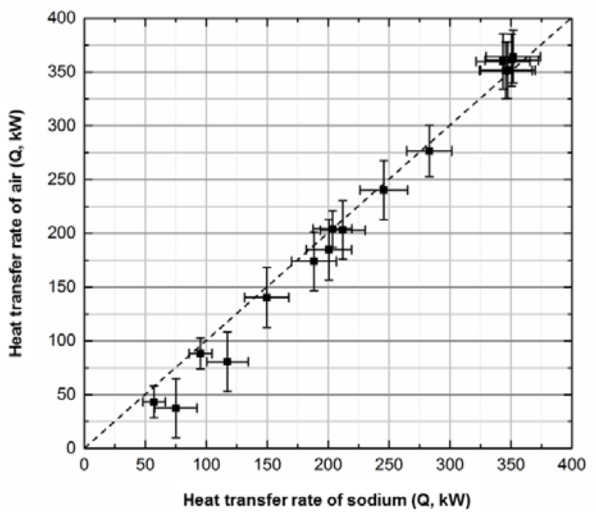

Fig. 4. Test results of heat transfer performances including the uncertainty

3. Conclusions

For verification of the performance of the FHX unit in a PGSFR, a separate effect test facility, called SELFA, was constructed and put into operation. Using this facility, heat transfer performance tests and their uncertainty analyses were carried out. Herein, we reported the first set of heat transfer performance tests including a conservative error analysis. The test results were represented very reasonably, and the quantities of error values were below 30 kW. Further analyses for the other set of experiments will proceed in the near future.

ACKNOWLEDGMENTS

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