Preliminary Evaluation of PGSFR DHR Heat Exchangers Performance Using STELLA-1 Facility

Jonggan Hong*, Jae-Hyuk Eoh, Sujin Yeom, Jewhan Lee, Tae-Joon Kim, Inkoo Hwang, Chungho Cho, Jong-Man Kim, Youngil Cho, Min-Hwan Jung, Da-Young Gam, Ji-Young Jeong
Korea Atomic Energy Research Institute, 989-111 Daedeok-daero, Yuseong-gu, Daejeon, 305-353, Korea
**Corresponding author: hong@kaeri.re.kr*

1. Introduction

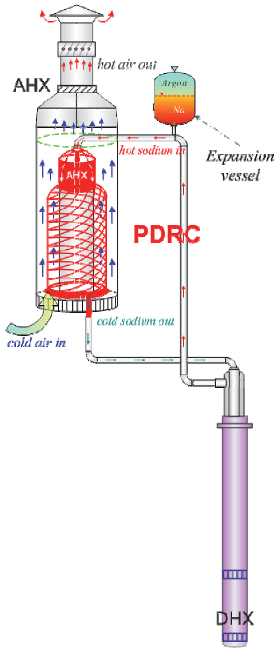
The STELLA program for PGSFR decay heat removal (DHR) performance demonstration is in progress at KAERI. As the first phase of the program, the STELLA-1 facility has been constructed and separate effect tests for heat exchangers of DHRS have been conducted [1]. Two kinds of heat exchangers including a shell-and-tube type sodium-to-sodium heat exchanger (DHX) and a helical-tube type sodium-to-air heat exchanger (AHX) were tested for design codes V&V, e.g. SHXSA and AHXSA.

In this paper, firstly, overall characteristics of the STELLA-1 facility are described briefly. Secondly, the performance tests of the DHX and AHX rely on a steady-state result of a heat transfer experiment. Thus experimental procedures to obtain the steady-state result are described and steady-state conditions for the heat exchanger performance test are clearly defined. Lastly, experimental results and calculation results obtained from the design codes are also compared as a preliminary work for the design code V&V.

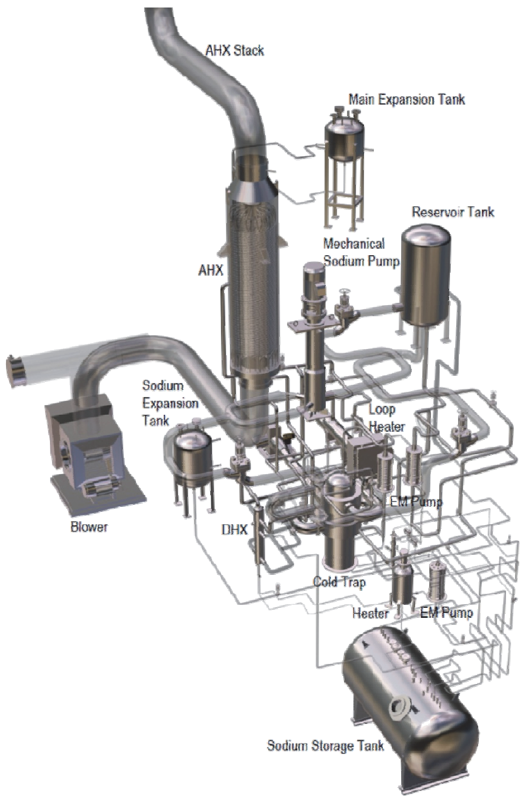
2. Methods and Results

2.1 Overall characteristics of the STELLA-1

PGSFR employs both active and passive DHR loops to cool down a sodium coolant system after reactor shutdown. The passive loop is equipped with the DHX and AHX to transfer the decay heat to ambient air (Fig. 1a). The STELLA-1 includes the two heat exchangers which belong to the passive DHR loop. A main test loop of the STELLA-1 consists of test components, including DHX, AHX, and a mechanical sodium pump, electrical loop heaters, a blower, electromagnetic pumps, buffer tanks, a sodium storage tank, etc (Fig. 1b). The STELLA-1 also has a sodium purification system, including a cold trap and a plugging meter, and auxiliary systems such as gas supply & vacuum systems, a power supply system and a fire protection system (Fig. 1b). Design temperature and pressure are 600 ℃ and 10 bar. Total sodium inventory in the sodium storage tank is about 18 tons. Total electric power given to the STELLA-1 is maximum 2.5 MW. The test heat exchangers of the STELLA-1 were originally scaled from a 600 MWe demonstration reactor. The scale ratio was determined to be unity for the height and 1/9 for power level. Although the core thermal output of the reference plant has been changed, its key design concepts of 150 MWe PGSFR including the DHR



(a)



(b)

Fig. 1 Schematic diagrams of (a) the passive decay heat removal system and (b) a layout of the STELLA-1.

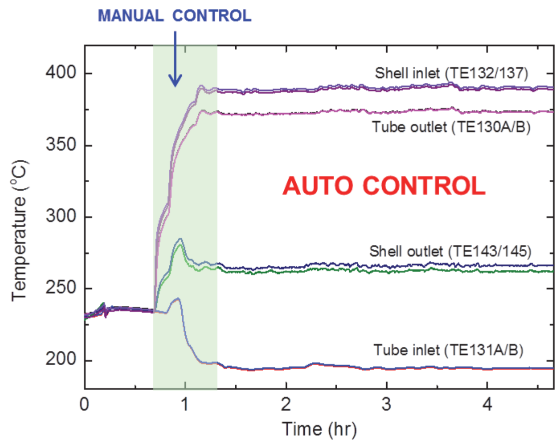
system are still identical to the 600 MWe demonstration reactor. To this end, the STELLA-1 tests have been focused on the heat exchanger codes V&V regardless of the prototype plant.

2.2 Theoretical calculation using the design codes

The heat transfer performance of the DHX and AHX was estimated from the design codes. SHXSA and AHXSA codes were developed for thermal sizing and performance analysis of the DHX and AHX, respectively. In the case of the SHXSA, the Schad-modified correlation was used for the shell-side heat transfer [2], and the Lyon-Martenelli correlation for the tube-side heat transfer [3]. In the case of the AHXSA, the Zhukauskas correlation was adopted for the shell-side heat transfer of air flow [4], and the Lubarski-Kaufman correlation for the tube-side heat transfer for sodium flow [5].

2.3 Steady-state tests

Total eight target operation points, four for the DHX test and four for the AHX test, were chosen based on the calculation results obtained from SHXSA and AHXSA codes, reflecting the operation temperature and flow rate ranges of the PGSFR. To reach the steady-state at the target operation point, mass flow rates of the shell- and tube-sides were adjusted by the



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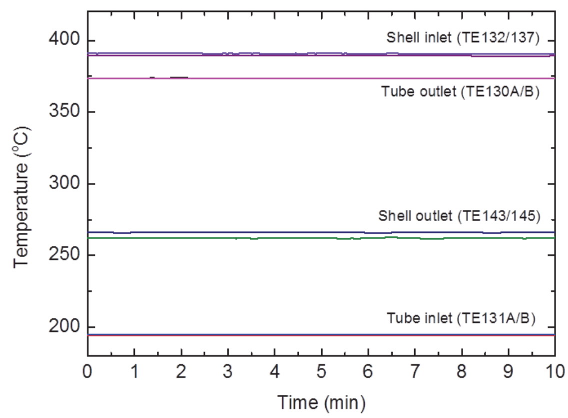
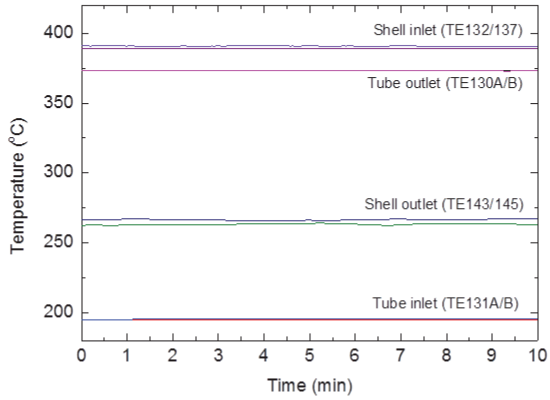


(b)

Fig. 2 Typical DHX temperature trends to reach the steady-state at a design point; (a) a transitional period by manual and auto control modes and (b) a steady-state for 10 min.



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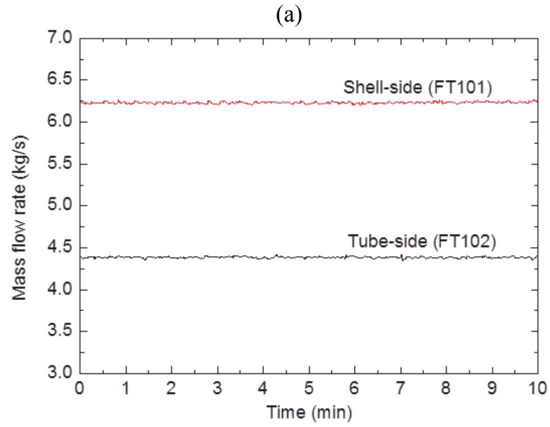

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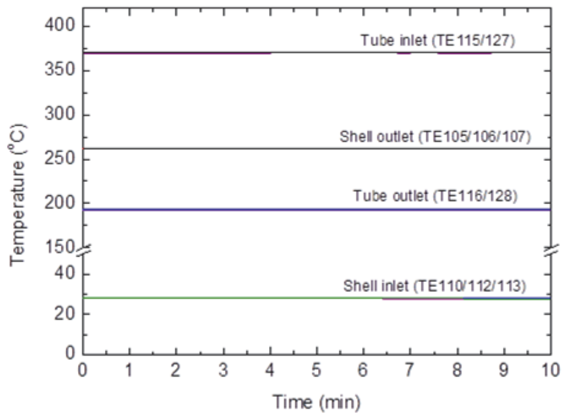

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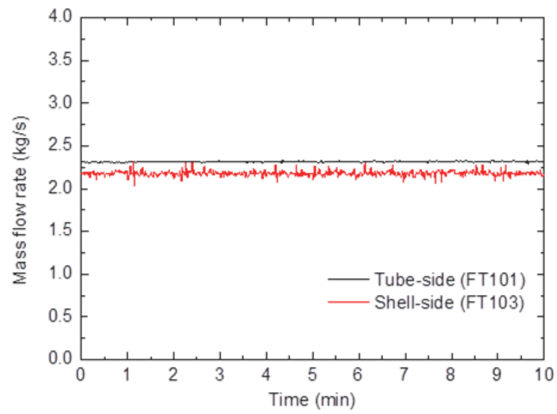

(d)

Fig. 3 Graphs of the typical steady-state for 10 min; (a) DHX temperatures, (b) DHX mass flow rates, (c) AHX temperatures and (d) AHX mass flow rates at the design point.

electromagnetic sodium pumps or air blower, and then inlet sodium temperatures of the shell- and tube-sides were controlled by using the electrical loop heaters. Because there was no device to regulate the inlet air temperature of the shell-side of the AHX, the intake air temperature was changed by the weather condition. The temperature control of the inlet temperature can be divided into two parts (Fig. 2). The first part is a manual control mode, and the power of the loop heaters and blower were controlled manually in this period (boxed area in Fig. 2a). After all the temperatures were getting close to target values, the mode was changed to an automatic operation mode. The steady-state condition was clearly defined for a judgment. The inlet and outlet temperatures of the heat exchanger have to fluctuate within an allowable limit, ±1 ℃, and the mass flow rates of the sodium and air have to fluctuate within allowable limits, ±0.1 kg/s and ±0.2 kg/s, respectively. It took several hours to reach the steady-state. Consequently, outlet temperatures of the shell- and tube-sides could be obtained after the steady-state for 10 min was achieved (Fig. 2b). The DHX and AHX tests were repeated three times at one target operation point. It is noted that identically repeated tests were not carried out on the same day to check whether the reproducibility changes day by day or not.

2.4 Comparison between the experimental results and calculation results

The result of the heat exchanger performance test showed a good reproducibility and a stable steady-state. Fig. 3 displays the trends of the typical steady-state for 10 min at the design point of the DHX and AHX. The temperatures and flow rates satisfied the criterion for a judgment of the steady-state. The nominal values of the 10 min steady-state were obtained and compared with the prediction of the design codes. The inlet temperatures and flow rates of the shell- and tube-sides were input values in the design codes and were set to be identical to the values obtained from the experiments. Accordingly, the outlet temperatures and power of the shell- and tube-sides, which are output values in the design codes, were quantitatively compared. The results of the representative comparison at the design point are shown in Table 1. The experimental results of the DHX showed good agreement with the prediction of the SHXSA code. The experimental results of the shell-side of the AHX were deviated a little bit from the prediction of the AHXSA, but the marginal discrepancy was found to be less than around 10%. The heat loss in the shell-side, radiation effect, experimental error, etc will be evaluated to figure out the discrepancy in the air flow of the AHX.

Table 1 Typical comparison between the experiment and theoretical calculation at the design point.

	DHX with SHXSA			AHX with AHXSA		
	Exp.	Cal.	Diff.	Exp.	Cal.	Diff.
Shell inlet temp., ℃	390.1	390.1	N/A	28.0	28.0	N/A
Tube inlet temp., ℃	194.9	194.9	N/A	370.2	370.2	N/A
Shell flow rate, kg/s	6.23	6.23	N/A	2.18	2.18	N/A
Tube flow rate, kg/s	4.39	4.39	N/A	2.33	2.33	N/A
Shell outlet temp., ℃	264.9	265.4	+0.5 (+0.2%)	262.2	285.3	+23.1 (+8.8%)
Tube outlet temp., ℃	373.3	370.1	–3.2 (–0.9%)	192.9	190.6	–2.3 (–1.2%)
Shell-side power, MW	1.01	1.01	0.0 (0.0%)	0.498	0.550	+0.052 (+10%)
Tube-side power, MW	1.03	1.01	–0.02 (–1.9%)	0.543	0.550	+0.007 (+1.3%)

3. Conclusions

The PGSFR DHR heat exchangers performance was experimentally demonstrated using the STELLA-1 facility, and the experimental results and the prediction of the design code were compared as a preliminary work for the design code V&V. The experimental results of the DHX and AHX were in good agreement with the estimation of the SHXSA and AHXSA codes, respectively.

ACKNOWLEDGMENTS

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