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Overview of Commissioning Test of LAPLACE Test Facility

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1. Introduction

The PAFS (Passive Auxiliary Feedwater System) is one of the advanced safety features adopted in APR+ (Advanced Power Reactor Plus), which is intended to completely replace the conventional active auxiliary feedwater system [1,2]. With an aim of validating the cooling and operational performance of the PAFS, the experimental program of the 1/16 scaled separate effect test is in progress at KAERI (Korea Atomic Energy Research Institute). The test facility, LAPLACE (Large Scale PAFS Loop for Assessment of Condensation Effectiveness) was constructed to experimentally investigate the condensation heat transfer and natural convection phenomena in the 1/16 scaled PAFS [3]. The major components and systems are ready for a quasi-steady state test, startup test, and various kinds of commissioning activities were performed.

2. LAPLACE Test Facility

2.1 Overview

KAERI conducted the separated effect test using PASCAL facility, which simulated a single tube among 240 tubes in the prototype in 2012 [4,5]. LAPLACE test facility simulates 15 heat exchanger tubes in consideration of the bundle effect of the PCHX. In addition, it was constructed for the purpose of prior study to resolve pending issues before the construction of the nuclear power plant. By performing the LAPLACE test, the major thermal-hydraulic parameters, such as local/overall heat transfer coefficients, fluid temperature inside the tube, wall temperature of the tube, and pool temperature distribution in the PCCT will be produced to evaluate the condensation heat transfer capability.

2.2 Test Facility

LAPLACE test facility was designed according to a volumetric scaling methodology [3]. The methodology can preserve the elevation change between a heat source and a heat sink in a natural circulation loop under the same pressure and temperature conditions of the prototype. LAPLACE test facility simulates 15 tubes among 240 tubes in the prototype, that is, the volumetric scaling ratio of the facility is 1/16. In order to preserve natural convection flow in the PCCT, the height of the pool is determined to be same as that of the prototype. Major scaling parameters of the LAPLACE test facility are compared with those of the prototype in Table I.

Figure 1 shows a schematic diagram of the LAPLACE test facility. A 10 MW steam generator in the LAPLACE test facility plays a role in supplying saturated steam to the PCHX tube. An electrical heater in the steam generator provides a heat source which scaled down the heat transfer rate at U-tube surface in the prototype. To preserve a driving force of the natural convection in the loop, a distance between the mixture level in the steam generator and the bottom of the PCCT is maintained to be equivalent to that of the prototype. The steam generator is connected to the PCHX tube with a steam-supply line and a return-water line.

In the LAPLACE test, major measuring parameters are the flow rate of the steam and condensate liquid, the loop temperature and pressure, the differential pressure on the steam-supply line and return-water line. Also, the collapsed water level and the liquid temperature are measured in the PCCT pool. In order to study the local distribution of the heat flux and the heat transfer coefficient of the PCHX, the surface temperatures at the inside and the outside wall were measured at two points along the tube length for three of the 15 tubes. At each point, the fluid temperature was also measured.

Table I: Scaling Parameter of the LAPLACE Test Facility

Parameter		APR+ PAFS	LAPLACE	Ratio
PCHX	Inner / Outer diameter	44.8 mm / 50.8 mm	44.8 mm / 50.8 mm	1/1
	Length	8.45, 8.42, 8.45 m	8.45, 8.42, 8.45 m	1/1
	Number of tubes	240	15	1/16
PCCT	Pool height	8.99 m	8.99 m	1/1
	Pool length	19.35 m	1.2 m	1/16
	Pool width	14.94 m	5 m	1/3
	Elevation from SG level to PCCT bottom	16 m	16 m	1/1
Operating Condition	Steam pressure	8.4 MPa	8.4 MPa	1/1
	Steam flow rate	91.72 kg/s	5.73 kg/s	1/16
	Thermal power	129.8 MW	8.1 MW	1/16

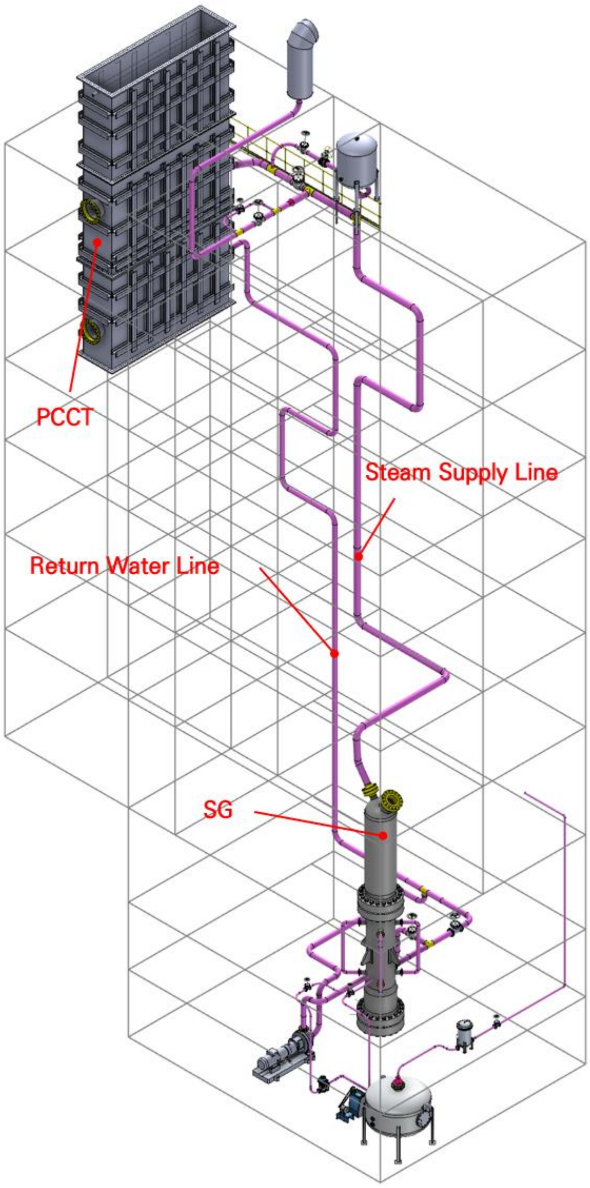
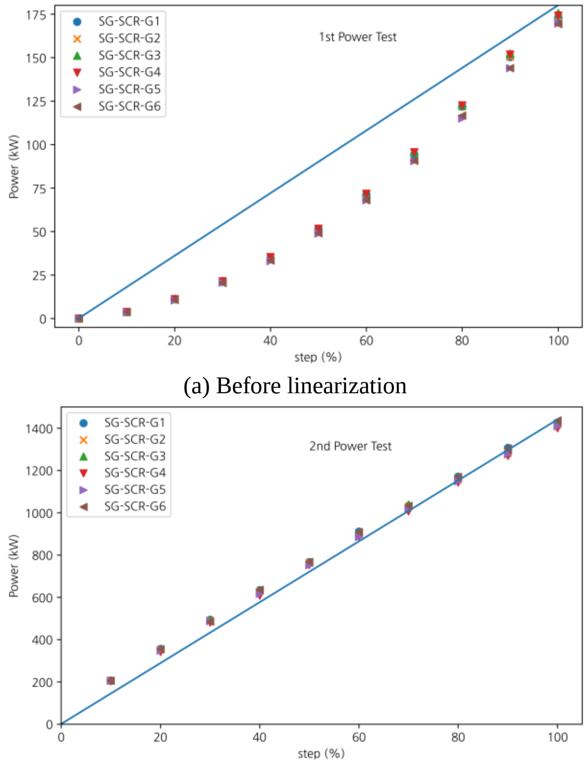


Fig. 1. Schematic diagram of the LAPLACE test facility.

3. Commissioning Test

3.1 Commissioning Activities

After completion of the loop cleaning activity, various kinds of stand-alone functional tests for all pumps and air-operated valves were performed. The key points for these components are the rotational directions fitted to their performance. In the case of canned motor pump, e.g., the main loop circulation pump, a rotational check was performed when the system was completely filled. For the 10 MW electrical heater, the main power was disconnected from the VCB, and a no-load test was performed. After fixing the power curve versus the input signal during the no-load test, the electrical heater was connected and tested when the main system was circulated. Figure 2 shows the linearized power curve of the SCR controller for the 10 MW electrical heater.



(a) Before linearization

(b) After linearization

Fig. 2. Linearized power curve of the SCR Controller.

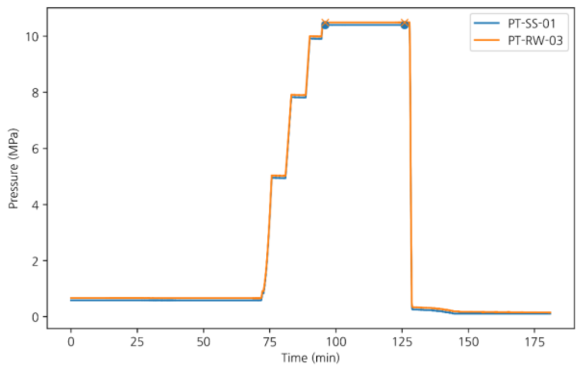


Fig. 3. Hydraulic leakage test results.

The following activities were filling each system with venting, which consists of static and dynamic venting. Dynamic venting was performed several times to minimize air bubbles in each system. For the main loop venting, the canned motor pump was used for dynamic venting under 0.5 MPa. After venting, leakage tests were performed according to the design requirements of each system. Based on the leakage test, the hydraulic integrities of each system can be confirmed, which means 'ready for operation'. Figure 3 shows the leakage test results of the LAPLACE test facility.

3.2 Test Condition and Procedure

Figure 4 shows the whole operation condition of the commissioning test to verify the system integrity and to determine whether the natural convection flow was created. After the leakage test, the electrical heater heated up the main system and the liquid was continuously circulated by a canned motor pump. When the main system temperature increased up to a certain temperature, the forced convection flow was stopped by closing the flow control valve on the return water line. By discharging of the single-phase flow and steam flow through the silencer, the inventory of the steam generator was gradually decreased. When the collapsed water level of the SG became 4.1 m, the flow control valve in the discharging line was closed and the flow control valve in the return water line was opened. Then, the natural convection flow was formed in the main loop.

2.25 MW and 3.0 MW of thermal power were supplied in the steam generator heater as a commissioning test power. The water in the PCCT was maintained in the saturated state at an atmospheric pressure. In order to shorten the commissioning test time, the water level of the PCCT was maintained at 5.3 m lower than the normal operation water level of 8.99 m. When the pressure, temperature, and flow rate reached a steady state at the constant thermal power condition, the heat removal rate and the natural convection flow were measured.

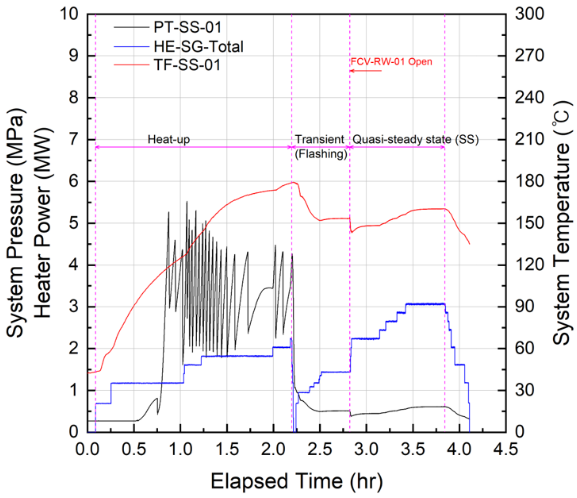


Fig. 4. Operation condition of the commissioning test.

3.3 Commissioning Test Results

Figures 5 and Figure 6 show the pressure and the temperature of the main loop, respectively. It is confirmed that the quasi-steady state condition was achieved when the pressure of the system (PT-SS-03) and the steam temperature (TF-SS-03) was reached to steady state. After the insulation on the piping, PCCT, and SG are completed, the heat balance test of the main system is planned to evaluate the heat loss from the piping and equipment.

Figure 7 shows the collapsed water level and coolant temperature of the PCCT. By a boiling heat transfer from the PCHX tube, the collapsed water level of the PCCT continuously decreased. The lower water level of

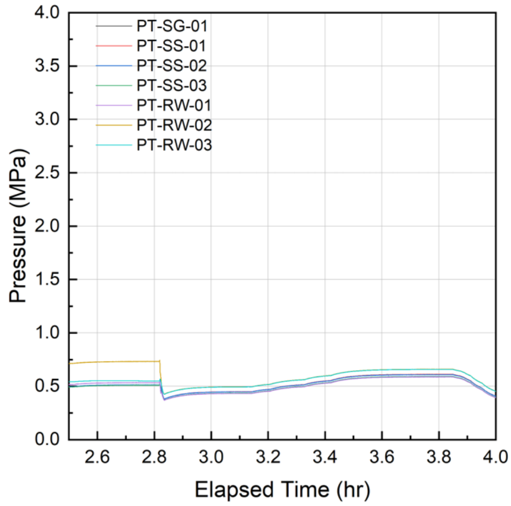


Fig. 5. System pressure of the commissioning test.

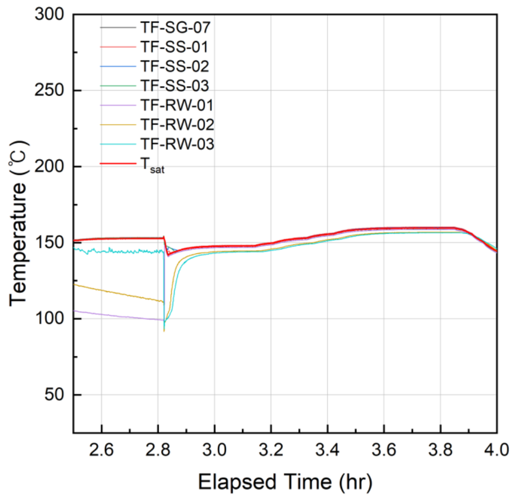


Fig. 6. System temperature of the commissioning test.

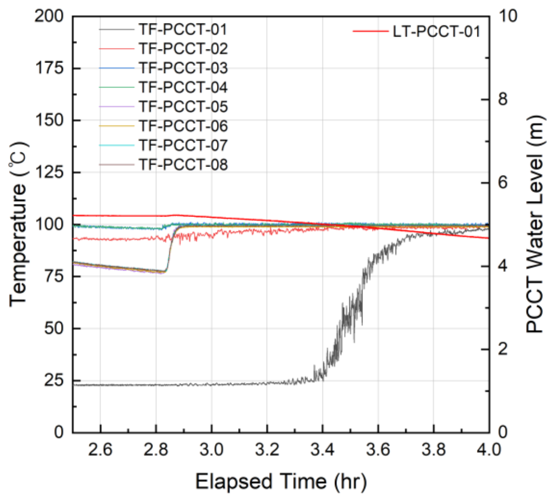


Fig. 7. Temperature and water level of the PCCT

the PCCT means the lower pressure and the lower saturation temperature of the pool water around the PCHX tube, so that a decrease of the PCCT water level resulted in a larger amount of the nucleate boiling on the tube surface. It made a boiling heat transfer coefficient at the outer wall of the tube increased. In the end, it can be seen that at the normal water level of PCCT, the boiling heat transfer of the PCHX is weakened than at low water level, and thus the main system pressure may increase.

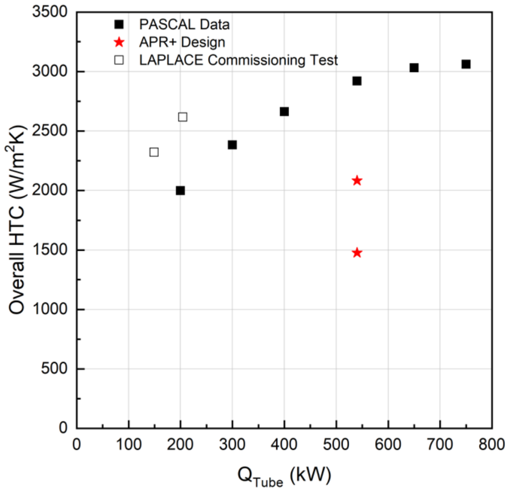


Fig. 8. Comparison of the overall HTC of PASCAL and LAPLACE.

Figure 8 shows the comparison of the overall heat transfer coefficient results of PASCAL and LAPLACE test. It can be seen that the overall heat transfer coefficient value is improved due to the bundle tube compared to the single tube. However, since the PCCT level was low in the commissioning test, the heat transfer coefficient value at the normal operation level of the PCCT is expected to decrease slightly.

4. Conclusions

Through a commissioning test of LAPLACE test facility, the integrity of each controller and the performance of the measuring instrument were verified. In addition, it was checked whether the natural convection flow was well formed according to the steam generator output. We plan to prepare for the main test by improving control and data storage systems.

The experimental results of LAPLACE will contribute to evaluate the model of the condensation and boiling heat transfer, and also to provide the benchmark data for validating the calculation performance of a thermal hydraulic system analysis code with respect to the PAFS.

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