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Experimental Study on the PAFS (Passive Auxiliary Feedwater System) during the Quasi-steady State and the MSSV Open

Byoung-Uhn Bae*, Seok Kim, Yu-Sun Park, Bok-Deuk Kim, Kyung Ho Kang
Thermal Hydraulics Safety Research Division, Korea Atomic Energy Research Institute
1045 Daedeok-daero, Yuseong-gu, Daejeon, 305-353, Republic of Korea
** Tel: +82-42-868-2597, Fax: +82-42-868-8362, Email:bubae@kaeri.re.kr*

1. Introduction

APR+ (Advanced Power Reactor Plus) is a GEN-III+ nuclear power plant being developed in Korea. The PAFS (Passive Auxiliary Feedwater System) is one of the advanced safety features adopted in the APR+, which is intended to completely replace the conventional active auxiliary feedwater system.[1] With an aim of validating the cooling and operational performance of the PAFS, the experimental program of the separate effect test is in progress at KAERI (Korea Atomic Energy Research Institute).[2] The test facility, PASCAL (PAFS Condensing heat removal Assessment Loop) was constructed to experimentally investigate the condensation heat transfer and natural convection phenomena in the PAFS. In this study, six tests were performed for validating cooling performance of the PAFS during a quasi-steady state. With a given thermal power of electrical heaters in the steam generator from 200 kW to 750 kW (SS-200-P1, SS-300-P1, SS-400-P1, SS-650, and SS-750-P1), a heat removal rate in the PCHX was measured and the characteristics of the natural convection in the loop were investigated. In the test of MSSV open, the thermal hydraulic behavior in the system was investigated after an abrupt open and close of the MSSV.

2. Test Facility

PASCAL facility was designed according to a volumetric scaling methodology [5]. 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.

PASCAL facility simulates a single tube among 240 tubes in the prototype, that is, the volumetric scaling ratio of the facility is 1/240. The volume of PCCT pool was also reduced to 1/240 of the prototype. The length and the width of the PCCT in the PASCAL facility is 6.7 m and 0.112 m, respectively And the height of the PCCT is 11.484 m.

Figure 1 shows the three-dimensional view of the PASCAL facility. A steam generator in the PASCAL facility plays a role in supplying saturated steam to the PCHX tube. An electrical heater in the steam generator provides a heat source which was scaled down the heat transfer rate at U-tube surface in the prototype steam generator. The maximum thermal power of the heater is 800 kW. To preserve a driving force of the natural convection in the loop, a elevation difference between the mixture level in the steam generator and the PCHX tube was maintained to be equivalent to that of the prototype. The steam generator was connected to the PCHX tube with a steam-supply line and a return-water line.

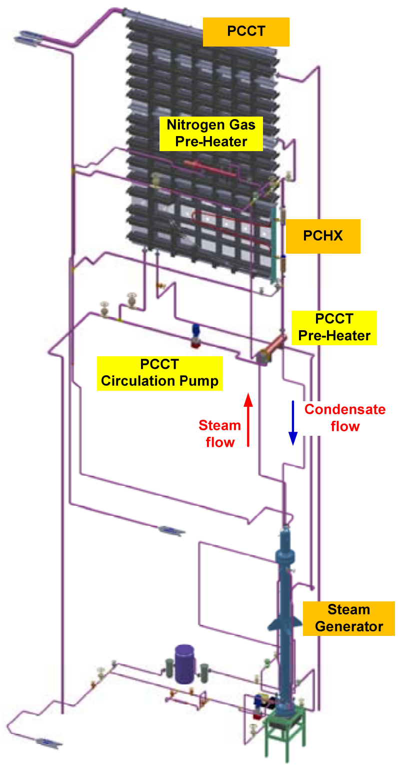

Fig. 1 3-D view of the PASCAL

3. Experimental Result

3.1 Test for the quasi-steady state

The separate effect test for validation of the cooling performance of the PAFS was performed. As sensitivity studies for a variation of the thermal power, test conditions for a quasi-steady state test (SS) were selected with a heater power of 200 kW, 300 kW, 400 kW, 540 kW, 650 kW and 750 kW.(SS -200-P1, SS-300-P1, SS-400-P1, SS-540-P1, SS-650-P1 and SS -750-P1)

Figures 1 and 2 plotted the steam pressure and temperature at the quasi-steady state condition according to a variation of the thermal power in SG. Since the maximum pressure in the SS-750-P1 test was near 6.7 MPa, it was concluded that the PASCAL facility could cover a whole operating region of the PAFS. Also, it was experimentally proved that the PAFS had an enough thermal margin.

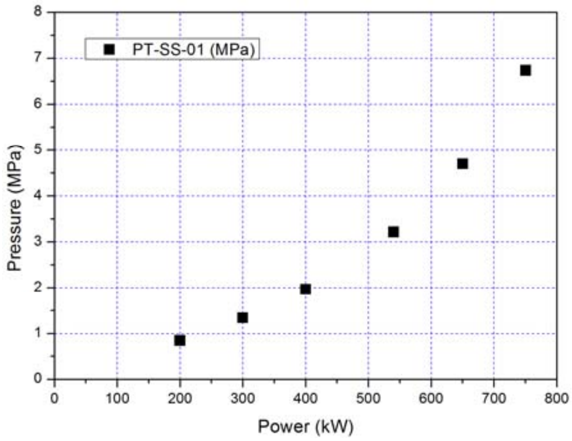

Fig. 1Steam pressures in the quasi-steady state test

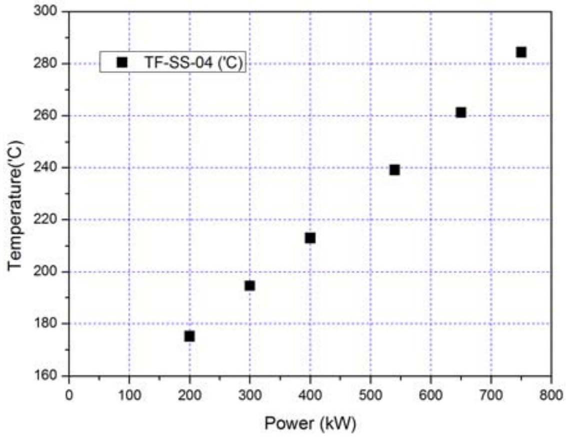

Fig. 2 Steam temperatures in the quasi-steady state test

3.2 Transient test for the MSSV open

In the MO-540-P1 test, the MSSV was open 3 times during the quasi-steady state condition of the SS-540-P1. Figure 3 showed the transient of the valve position of the MSSV. The thermal hydraulic behavior during the opening and closing the MSSV was experimentally investigated.

When the MSSV was opened, the natural convection flow presented an oscillating behavior due to the steam discharge through the MSSV line to the atmosphere as shown in Fig. 4. Even though the system pressure was decreased and the flow rate in the loop showed the oscillating trend, overall thermal hydraulic behavior in the PAFS loop became stabilized after closing the MSSV. It means that the cooling performance has been effectively recovered after the steam discharge to the atmosphere through the MSSV. From the MO-540-P1 test, the operating capability of the PAFS during an abrupt open and close of the MSSV was proved.

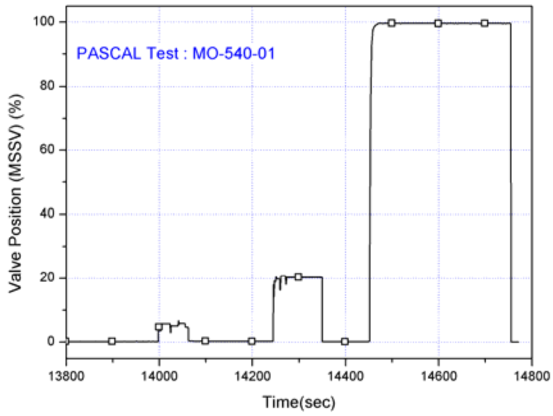

Fig. 3 Valve position of MSSV in MO-540-P1 test

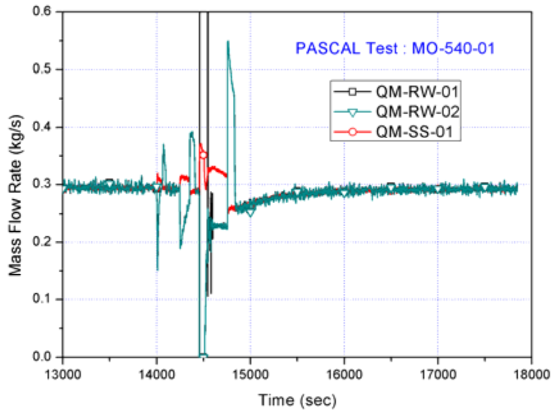

Fig. 4 Flow rate of MO-540-P1 test

3. Conclusions

This study focused on the experimental result with the PASCAL facility to validate the cooling and operational performance of the PAFS. From the experimental results, it was found that the current design of the PCHX satisfied the heat removal requirement for cooling down the reactor core during an accident condition. In case of the abrupt open and close of the MSSV valve, the PAFS showed a stable behavior in cooling down the decay heat. Therefore, it is concluded that PAFS can replace a conventional active AFWS(Auxiliary Feedwater System) in APR+ nuclear power plant, utilizing the natural convection flow driven by the natural convection of two-phase flow.

REFERENCES

[1] J. Cheon et al., "The Development of a Passive Auxiliary Feedwater System in APR+ Track 1: Water-Cooled Reactor Programs & Issues", Proceedings of ICAPP'10, June 13-17, San Diego, CA, USA (2010)
[2] B.J. Yun et al., Construction Report of Separate Effect Test Facility for PAFS, KAERI/TR-4085/2010 (2010)