Simulation of Transient Scenarios for Passive Auxiliary Feedwater System in APR+

Byoung-Uhn Bae*, Seok Kim, Yu-Sun Park, 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

A passive safety system, PAFS (Passive Auxiliary Feedwater System), is considered for improvement of the safety in designing APR+ (Advanced Power Reactor Plus), which is a GEN-III+ nuclear power plant being developed in Korea. To validate the cooling and operational performance of the PAFS, a separate-effect test facility named as PASCAL (PAFS Condensing heat removal Assessment Loop) has been constructed. [1,2]

In this study, postulated transient scenarios occurring in the PAFS were simulated to evaluate the operational performance of system and investigate the thermal hydraulic phenomena of the two-phase natural convection flow. The transient tests simulated in this study are PAFS start-up actuation test (SU) and non-condensable gas effect test (NC).

2. Test Facility

PASCAL facility was designed to be a full-height facility 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. Since a prototype of the PAFS has 240 tubes for the PCHX (Passive Condensation Heat Exchanger) and the PASCAL facility simulates a single tube among them as shown in Fig. 1, 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

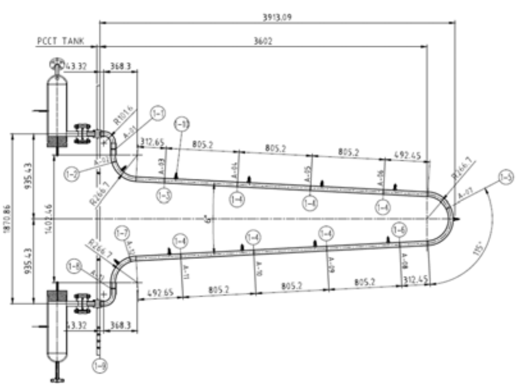

Fig. 1 Design of PCHX of PASCAL facility

The PASCAL facility has a steam generator to supply saturated steam to the PCHX tube. Electrical heaters in the steam generator provide a heat source which 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, an 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. The natural convection loop with the steam-supply line and the return-water line was designed to conserve pressure drop equivalently to the prototype.

3. Experimental Result

3.1 PAFS start-up actuation test (SU)

At the moment of initial actuation of the PAFS, the highly subcooled coolant contained in a pipe of the return-water line can abruptly flow into the steam generator with opening an actuation valve. It can induce instability in the natural convection loop, so that a transient condition for the initial actuation of the PAFS was simulated with SU-540-P1 test in the PASCAL facility.

In the experiment, the actuation valve at the return-water line was opened at 586 sec, so that the liquid in the return-water line flowed downward to the steam generator by gravity. It increased a mass flow rate in the return-water line as shown in Fig. 2. Even though the steam flow rate in the steam-supply line showed fluctuations at an initial period after opening the actuation valve, the mass flow rate of the steam and the water was converged to an equivalent value. That means the PAFS system can operate without any significant instability in the natural convection loop. During the natural convection, the highly subcooled water contributed to cool down the system and reduce the system pressure.

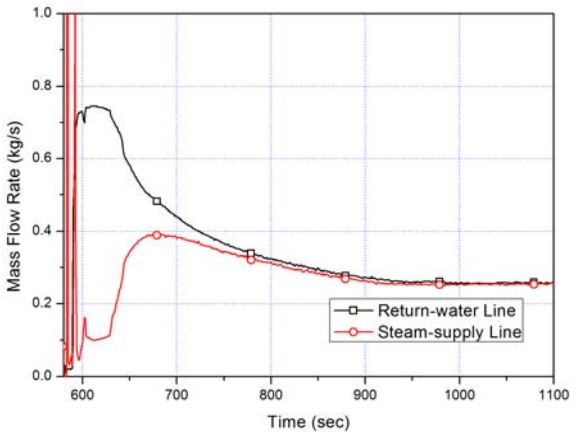

Fig. 2 Flow rate of SU-540-P1 test

3.2 Non-condensable gas effect test (NC)

To investigate the effect of non-condensable gas effect in the heat exchanger, nitrogen gas was gradually injected in the NC-540-P1 test. The total amount of the nitrogen gas which was injected to the system was 0.1087 kg during about 50 seconds. Figure 3 showed the system pressure variation. As the nitrogen gas was injected, the system pressure was increased. After terminating the injection of the gas, the system pressure did not increase anymore and it was kept steadily. Figure 4 presented the mass flow rate of the steam supply line and the return water line. The steam flow rate in the steam-supply line was decreased initially due to the retardation of the steam flow by the injected gas. The flow rate of the return-water line was also decreased by the decrease of the steam flow rate. The difference between two flow rates was disappeared within 300 seconds and the flow rates were stabilized.

Even though the injected non-condensable gas in this test was 60% larger amount than the possible amount in the prototype APR+, the disturbance of the system was stabilized in short time, 300 seconds and only 3% of the degradation of the heat transfer coefficient was shown. It means that the cooling performance of the PAFS does not affected significantly by the existence of the non-condensable gas.

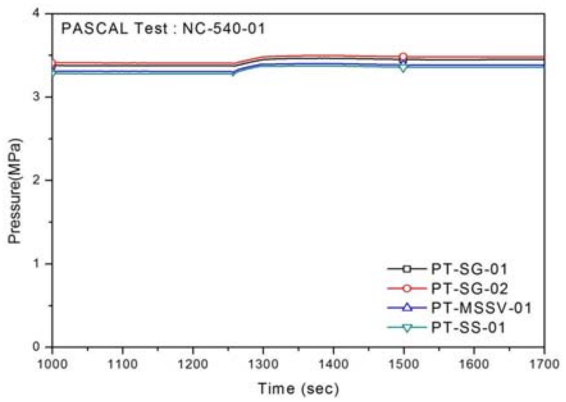

Fig. 3 System pressure of NC-540-01 test

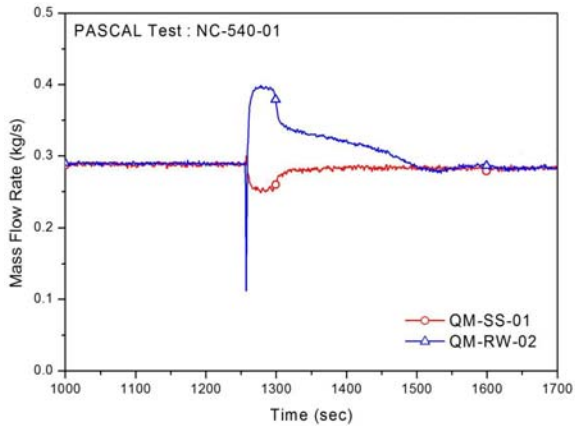

Fig. 4 Flow rate of NC-540-01 test

3. Conclusions

In this study, postulated transient scenarios occurring in the PAFS were simulated to evaluate the performance of the condensation heat transfer and investigate the thermal hydraulic phenomena of the two-phase natural convection flow. Start-up actuation test simulated the initial transient when the PAFS actuation signal was generated and the natural convection flow was initiated in the loop, and any significant two-phase flow instability was not observed in the test. The purpose of the non-condensable gas effect test is to study the characteristics of the condensation heat transfer in the heat exchanger when the nitrogen gas was injected. The test results proved that the existence of the non-condensable gas up did not produce a meaningful decrease of the cooling capability in the PAFS. From the experimental results described above, the cooling and operating performance of the PAFS was validated with respect to occurrence of the various transient scenarios and it was proved that the function of the PAFS can be effectively performed during the transient situation. The result will be also utilized in validation of the thermal hydraulic system code in the future.

REFERENCES

[1] K.H. Kang, S. Kim, B.U. Bae, Y.J. Cho, Y.S. Park, B.J. Yun, "Separate and integral effect tests for validation for cooling and operational performance of the APR+ passive auxiliary feedwater system", Nuclear Engineering and Technology, vol. 44 (6), 2012

[2] B.J. Yun et al., Construction Report of Separate Effect Test Facility for PAFS, KAERI/TR-4085/2010, 2010

[3] B. U. Bae et al., "Scaling Analysis of Separate Effect Test Loop (PASCAL) for PAFS(Passive Auxiliary Feedwater System)", The Seventh Korea-Japan Symposium on Nuclear Thermal Hydraulics and Safety, November 14- 17, Chuncheon, Korea, 2010