# Experimental Program for Validation of Cooling and Operational Performance of the APR+ Passive Auxiliary Feedwater System

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## 1. Introduction

PAFS (Passive Auxiliary Feedwater System) is one of the advanced passive safety systems adopted in the APR+ (Advanced Power Reactor plus), which is intended to completely replace the conventional active auxiliary feedwater system. PAFS cools down the steam generator's secondary side, and eventually removes the decay heat from the reactor core by introducing a natural driving force mechanism; i.e., condensing steam in nearly-horizontal U-tubes submerged inside the passive condensation cooling tank (PCCT).

With an aim of validating the cooling and operational performance of the PAFS, an experimental program is in progress at KAERI (Korea Atomic Energy Research Institute), which is composed of two kinds of tests; the separate effect test and the integral effect test [1]. The separate effect test, PASCAL (PAFS Condensing Heat Removal Assessment Loop), is in progress to experimentally investigate the condensation heat transfer and natural convection phenomena in PAFS. The integral effect test is being performed to confirm the operational performance of the PAFS coupled with the other reactor coolant systems (RCS) using the thermal-hydraulic integral effect test facility, ATLAS (Advanced Thermal-hydraulic test Loop for Accident Simulation). This paper summarizes the up-to-date experimental results of the separate effect test and the integral effect test for PAFS from a cooling and operational performance point of view.

## 2. Separate Effect Test Program

Fulfillment of the heat removal requirement via PAFS was experimentally validated in the separate effect test, PASCAL. By performing the PASCAL 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, were produced not only to evaluate the current condensation heat transfer model, but also to present a database for the safety analysis related with PAFS. The PASCAL test is composed of 5 kinds of test items: Quasi-steady state heat transfer test (SS), PCCT level variation test (PL), inadvertent MSSV opening test (TR), PAFS actuation test (SU), and non-condensable gas effect test (NC). The SS and PL tests were completed, and the cooling and operational performance of PAFS is discussed based on the experimental findings of the SS and PL tests in this paper. The effect of non-condensable gas and the start-up transient of PAFS will be investigated in the frame of the PASCAL test from the middle of 2012.

As the steam flowed toward the outlet, the heat flux decreased, due to the lower wall temperature, which was induced by the subcooled liquid flow. Since the top part of the tube was filled with the steam flow and the condensate liquid flowed in the bottom region inside the tube, the condensation heat transfer coefficient at the top region of the inner wall was larger than that of the bottom region, as shown in Fig. 1. The phase distribution inside the PCHX can be confirmed from the fluid temperature contour plotted in Fig. 2. According to the distribution of the fluid temperature inside the PCHX, it was found that a stratified flow appeared along the whole length of the tube. Fig. 3 shows the steam pressure at the quasi-steady state condition, according to a variation of the thermal power in the SG. Since the maximum pressure was near 6.7 MPa in the case of the 750 kW applied test, it was concluded that the PASCAL facility could cover a whole operating region of PAFS. Also, it was experimentally proved that the present design of PAFS has an adequate thermal margin.

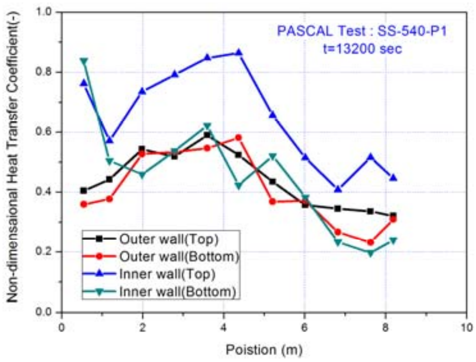


Fig. 1. Heat transfer coefficients at steady state condition.

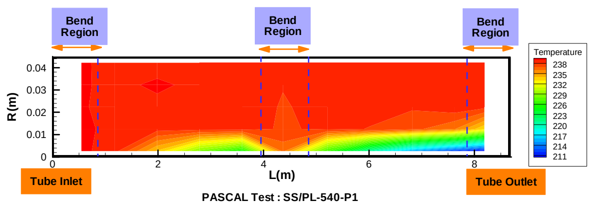


Fig. 2. Fluid temperature contour inside the PCHX.

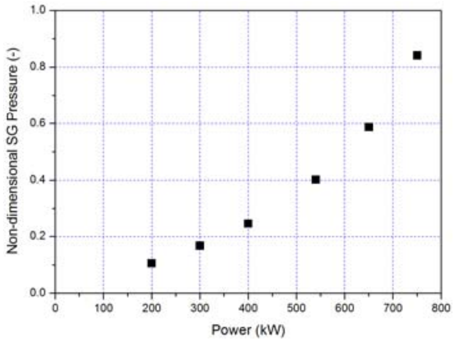


Fig. 3. Steam pressure according to the applied power.

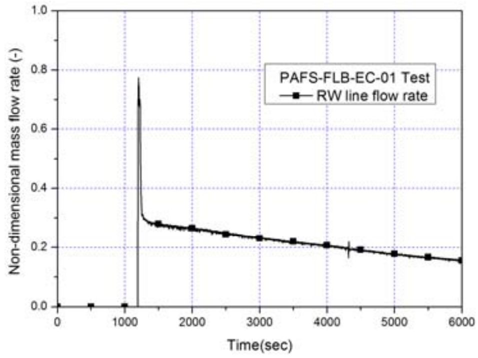


Fig. 4. Natural circulation flow of the PAFS.

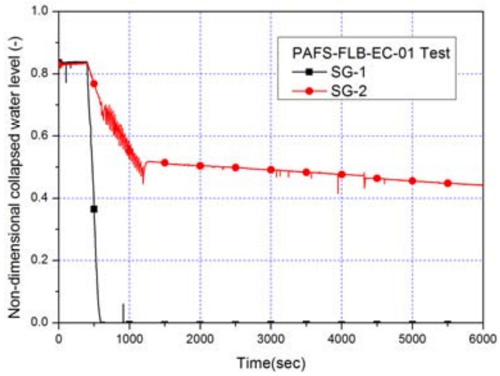


Fig. 5. Collapsed water levels in the SG secondary side.

## 3. Integral Effect Test Program

The main objective of the ATLAS-PAFS integral effect test is to investigate the thermal hydraulic behavior in the primary and secondary systems of the APR+ during a transient when PAFS is actuated. Since the ATLAS-PAFS facility simulates a single train of PAFS, the anticipated accident scenarios in the experiment include FLB (Feedwater Line Break), MSLB (Main Steam Line Break), and SGTR (Steam Generator Tube Rupture). As the first integral effect test in the frame of the ATLAS-PAFS experimental program, the test for simulating an FLB was performed in this study.

The initial steady-state conditions and the sequence of event in the FLB scenario for the APR+ were successfully simulated with the ATLAS-PAFS facility. When the reactor was tripped, both the reactor coolant pump (RCP) and the turbine were stopped concurrently The main steam isolation valve (MSIV) of each steam generator was closed right on an actuation of a low steam generator pressure (LSGP) trip signal. The water level of the affected steam generator (SG-1) decreased rapidly to empty due to the break flow. Contrary to the SG-1, the water level of the intact steam generator (SG-2) decreased continuously and reached the set-point of the passive auxiliary feedwater actuation signal (PAFAS), 25% of the wide range (WR) water level.

Fig. 4 shows a natural circulation flow measured at the return-water line during the PAFS actuation. When the PAFS actuation valve was open, the water in the return-water line and the PCHX drained to the SG-2 through the economizer nozzle, so that the mass flow rate measured by a flow meter at the return-water line showed a peak value of 0.775 kg/s at 1205 seconds, as shown in Fig. 4, and the collapsed water level of the SG-2 increased to 3.1 m, as presented in Fig. 5. After the drainage of the coolant in the return-water line and the PCHX, the natural convection flow in the PAFS loop was stably formed without any instability until the end of the transient as shown in Fig. 4. From the present experimental result, it could be concluded that the APR+ has the capability of coping with the hypothetical FLB scenario by adopting PAFS and the proper set-points of its operation.

## 4. Conclusions

Experimental programs have been launched with an aim of validating the cooling and operational performance of the APR+ PAFS. For an effective and comprehensive evaluation, the validation experiment is composed of two kinds of test: i.e. a separate effect test and an integral effect test. The present separate effect test result proved that the current design of the PCHX satisfied the heat removal requirement of the APR+ PAFS for cooling down the reactor core during the anticipated accident transients. In the integral effect test, as PAFS actuated, the natural convection flow in the PAFS loop was formed without any instability, and the collapsed water level in the intact steam generator was maintained steadily. The pressure and the temperature of the primary system continuously decreased during the heat removal by the PAFS operation. From the present experimental result, it could be concluded that the APR+ has the capability of coping with the hypothetical FLB scenario by adopting PAFS and the proper set-points of its operation.

## REFERENCES

[1] K. H. Kang, et al. "Separate and Integral Effect Tests for Validation of Cooling and Operational Performance of the APR+ Passive Auxiliary Feedwater System," *Nuclear Engineering and Technology*, Vol. 44, No. 6, August 2012.