Passive Condensation Cooling Tank (PCCT) Water Level Effect for Cooling Performance of Passive Auxiliary Feedwater System (PAFS)

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1. Introduction

APR+ (Advanced Power Reactor Plus) is a next generation nuclear power plant being developed in Korea. It adopts PAFS (Passive Auxiliary Feedwater System) for the steam generator (SG) instead of an active auxiliary feedwater system for the conventional nuclear power plant (NPP). The passive safety system is advantageous in that it can enhance the reliability and reduce the effect of operator mistakes, which have been fundamental weak points as indicated in the safety analysis including the PSA (Probability Safety Assessment).

The PAFS can replace the conventional active auxiliary feedwater system for the SG by a passive way [1]. A schematic diagram of the PAFS for the APR+ is shown in Figure 1. It is composed of a steam-supply line, a condensation heat exchanger, a return-water line, and a PCCT (Passive Condensate Cooling Tank). When the water level in the SG becomes lower than 25% of the wide range of the water level transmitter during an accident situation, the actuation valve at the return-water line is open and then the natural convection flow of the PAFS can be made. It cools down the secondary system of the SG by heat transfer at the condensation heat exchanger installed in the PCCT. The steam generated from the SG in the high pressure condition is condensed in the condensation heat exchanger tube. The absolute pressure at the top of PCCT is maintained at an atmospheric pressure, so that natural convection accompanying boiling heat transfer at the outside wall of the heat exchanger tubes occurs in the PCCT pool side. Since the heat exchanger and the PCCT are located at a higher elevation than the SG, condensate water can be returned back to the SG with a natural driving force.

From the experiment, two-phase flow phenomena in the horizontal heat exchanger and PCCT were investigated and the cooling capability of the condensation heat exchanger was validated. Test results showed that the design of the condensation heat exchanger in PAFS could satisfy the requirement for heat removal rate of 540 kW per a single tube and the prevention of water hammer phenomenon inside the tube.

2. Experiments

2.1 Test Facility

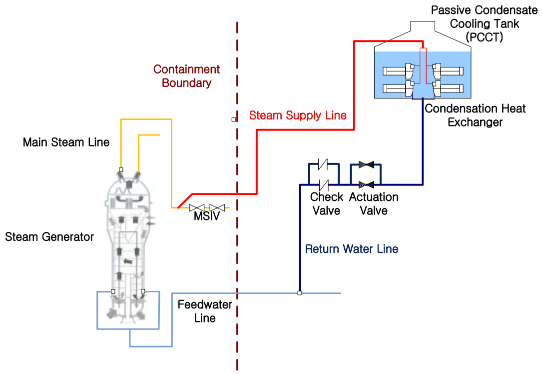

Fig. 1. Schematic diagram of PAFS in APR+.

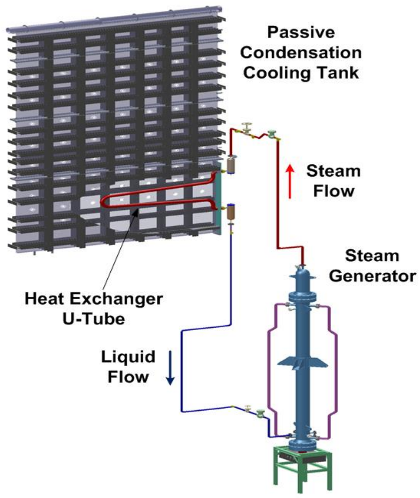

Fig. 2. Schematic diagram of PASCAL facility.

To validate cooling performance of PAFS, a separate effect test was performed with PASCAL (PAFS Condensing heat removal Assessment Loop) facility [2]. It simulates a single tube of the condensation heat exchangers, a steam-supply line, a return-water line, and a PCCT with a reduced area, which is equivalent to 1/240 of the prototype according to a volumetric scaling methodology with a full height. In order to conserve natural convection flow in PCCT, the height of the pool is determined to be same as that of the prototype. The length of PCCT in the PASCAL facility is 6.7m, which is a half of that of prototype, since the bundles are placed in two rows. So the width of PCCT was 0.112m, which is equivalent to 1/120 of that of prototype.

A steam generator in PASCAL facility plays a role in supplying saturated steam to the heat exchanger 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 steam generator. To conserve a driving force of the natural convection in the loop, a distance between the mixture level in the steam generator and the heat exchanger tube was maintained to be equivalent to that of the prototype. The steam generator was connected to the heat exchanger tube with a steam-supply line and a return-water line. Figure 2 shows the schematic diagram of PASCAL facility.

2.1 Test Results

The separate effect test for validation of the cooling performance of the condensation heat exchanger was performed according to the maximum heat removal condition of PAFS. Since it is required for a single system of PAFS to remove 129.8 MW as a maximum heat removal rate, the test condition was determined according to the scaling ratio of the facility. Therefore, 550kW of thermal power was supplied in the steam generator heater. The pool water was maintained as the saturated state at an atmospheric pressure. 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 was measured.

Figure 3 compares the heat removal rate on the steady state at the continuous thermal power of the steam generator heater for the steady state of 300 seconds. The figure presents that the supplied thermal power is effectively removed by the heat transfer at the condensation heat exchanger emerged in PCCT.

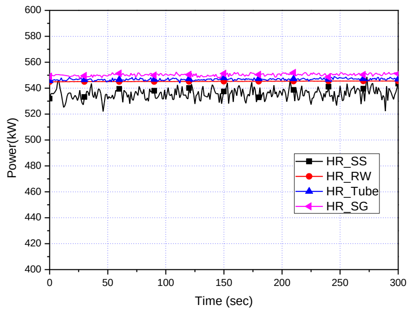

Fig. 3. Heat removal rate of PASCAL facility.

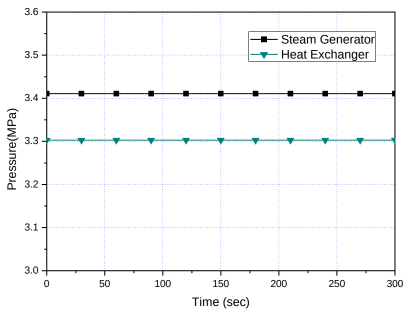

Fig. 4. System pressure in the steady-state experiment.

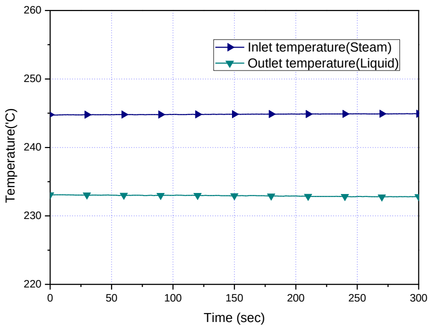

Fig. 5. Fluid temperature in the steady-state experiment.

Figures 4 and 5 show the pressure and temperature of the main loop, respectively. It is confirmed that the steady state condition was achieved when the pressure of the system reached 3.3 MPa and the steam temperature was 245℃ with the 550kW of thermal power. Considering that the heat exchanger of PAFS was designed to remove the decay heat at the steam condition of 7.4 MPa and 290℃, the experimental result proved that the current design of the condensation heat exchanger had an enough margin to cool down the reactor system without any active safety injection system.

3. Conclusions

In order to replace the conventional active auxiliary feedwater system with a passive way, the PAFS is being developed for the Korean APR+ nuclear power plant. The PAFS utilizes the condensation in the horizontal heat exchanger, the natural convection of the steam, and the boil-off of PCCT pool water. In this study, PCCT water level effect was investigated to satisfy its requirements for the heat removal capacity and the operational performance. The MARS calculation results confirm that the current design of the PAFS heat exchanger has a capability to cool down the required decay heat from the reactor core during decreasing PCCT water level.

ACKNOWLEDGMENTS

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