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Integral Effect Test on Operational Performance of PAFS for a SLB Accident

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1. Introduction

PAFS (Passive Auxiliary Feedwater System) is one of the advanced safety features adopted in the APR+ (Advanced Power Reactor Plus) which is intended to completely replace a conventional active auxiliary feedwater system. PAFS cools down the steam generator secondary side and eventually removes the decay heat from the reactor core by adopting a natural convection mechanism; i.e., condensing steam in nearly-horizontal U-tubes submerged inside the PCCT (Passive Condensation Cooling Tank). With an aim of validating the operational performance of PAFS, the experimental program of an integral effect test is in progress at KAERI (Korea Atomic Energy Research Institute). The test facility, ATLAS-PAFS was constructed to experimentally investigate the thermal hydraulic behavior in the primary and secondary systems of the APR+ during a transient when PAFS is actuated.

In this study, PAFS-SLB-GB-01 test was performed to simulate a guillotine break on the downstream of MSSV (Main Steam Safety Valve) connected to the SG-1, which was analyzed as a severe overcooling case in the APR+ SSAR (Standard Safety Analysis Report). With an aim of simulating a SLB accident of the APR+ as realistically as possible, a pertinent scaling approach was taken. The main objectives of this test were not only to provide physical insight into the system response of the APR+ during a SLB accident but also to produce an integral effect test data to validate a thermal hydraulic safety analysis code.

2. Experiments

2.1 Test Facility

A schematic diagram of ATLAS-PAFS 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). The steam-supply and the return-water line connect the PCHX to the steam generator of the ATLAS. In order to preserve a pressure drop of the facility to a half of the prototype, the pipe size was determined to be 1-1/2” for the steam-supply line, and 1-1/4” for the return-water line. Each line includes an orifice and a coriolis mass flowmeter. In particular, the return-water line was designed to scale down the volume of the prototype for conserving the inventory of the coolant.

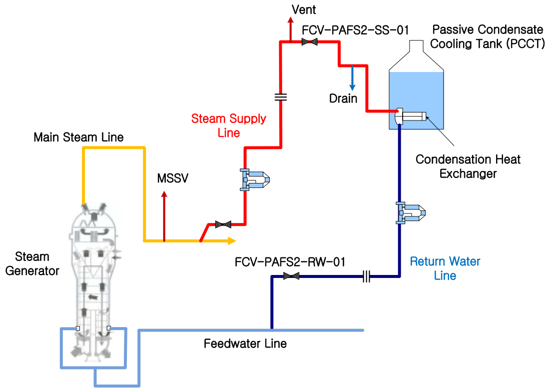

Fig. 1. Schematic diagram of ATLAS-PAFS.

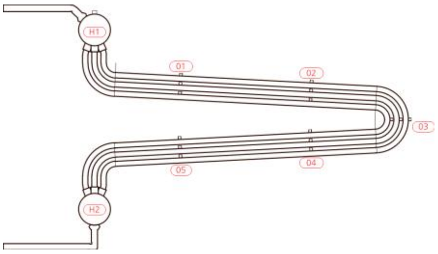

Fig. 2. Design of the PCHX (dimension in mm).

PCCT was designed as a rectangular pool, which has a half-height scale and a reduced area according to the global scaling ratio of the ATLAS. The PCCT is placed at the elevation of 17.3 m above the ground, which aims at conserving the level difference between the PCHX and the coolant surface in the SG-2. The PCHX is placed at the bottom region of the PCCT, where the center of the PCHX tube is 1.06 m above the PCCT bottom surface. When PAFS is actuated, heat transfer from the PCHX makes evaporation of the pool water in the PCCT, and the steam flows outside the building through a pipe on the top.

Figure 2 shows the design of the PCHX in the ATLAS-PAFS. The PCHX has three tubes which conserves the heat transfer rate at the surface according to the scaling methodology. A reduced diameter of the tube enabled the heat removal rate to be conserved in the facility. The tubes have the same material and the thickness to preserve the heat flux and the wall temperature. Top and bottom headers were designed to conserve the volume of the prototype. In order to prevent vibration of the PCHX tubes in the PCCT, the structure of the support bar was manufactured. On the inner wall and outer wall, the wall temperature was measured at five points along the tube length to estimate the wall heat flux and the heat transfer coefficient. Also, a fluid temperature profile inside the PCHX was measured by installation of the thermocouples in a vertical direction.

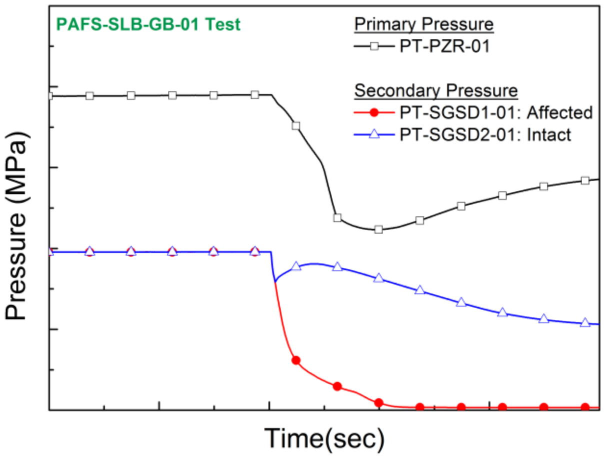

Fig. 3. Primary and secondary system pressure.

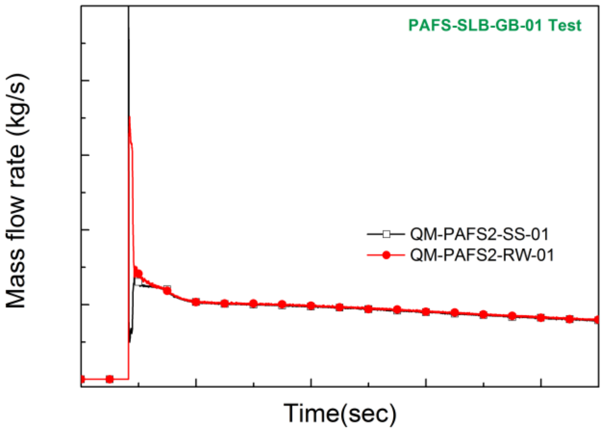

Fig. 4. Flow rate of the steam supply line and return-water line.

2.2 Test Results

Figures 3 show a pressure trend of the pressurizer and the steam generators. Coincidently with the break, main feedwater pump stopped and main feedwater was isolated. Both the RCP and the turbine were also stopped coincidently with the break due to LOOP assumption. The pressure of the primary system decreased during the initial period. SIP injection signal was produced by low pressurizer pressure (LPP) and the pressure of the primary system increased by SIP injection. In this study, PAFS actuated coincidently with reactor trip. PAFS was actuated and effectively cooled down the primary system by the condensation heat transfer occurred at the PCHX. The pressure of the intact SG continuously decreased during the heat removal by PAFS operation.

When the 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 (QM-PAFS2-RW-01) showed a peak value as shown in Figure 4. After the drainage of the coolant in the return-water line and the PCHX, the natural convection flow in PAFS loop was formed until the end of the transient as shown in Figure 4. The steam flow from the SG-2 was condensed by the heat transfer at the PCHX, and then the condensate liquid was returned back to the SG-2 through the economizer nozzle.

3. Conclusions

The initial steady-state conditions and the sequence of event of SLB scenario for the APR+ were successfully simulated with the ATLAS-PAFS facility. From the experiment, major thermal-hydraulic phenomena such as the system pressures, the collapsed water levels, the break flow rate, and the condensate flow rate in PAFS were investigated and discussed. Following the reactor trip induced by LSGP (Low Steam Generator Pressure) signal, PAFS was immediately actuated and effectively cooled down the primary system by the condensation heat transfer occurred at the PCHX (Passive Condensation Heat Exchanger). The pressure and the temperature of the primary system decreased continuously during the heat removal by PAFS operation. The water pool in the PCCT was heated up to the saturation condition and the evaporation of the water made a decrease of the PCCT water level. It could be concluded from the present experimental result that the APR+ PAFS has the capability of coping with the hypothetical SLB scenario and the proper set-points of its operation. This integral effect test data will be used to evaluate the prediction capability of existing safety analysis codes such as MARS or SPACE codes and to identify any code deficiency for a SLB simulation with an operation of PAFS.

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