Design and Pre-Test Scoping Analysis for a Large Scale PAFS Test Facility

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1. Introduction

One of the evolutionary safety systems adopted in APR+ (Advanced Power Reactor Plus) is PAFS (Passive Auxiliary Feedwater System) which removes the decay heat of the reactor core by a natural circulation in the steam generator secondary system [1]. The steam generated in the steam generator is condensed in the PCHX (Passive Condensation Heat Exchanger) that is submerged inside of a large water pool, i.e., PCCT (Passive Condensation Cooling Tank).

For a validation of the operational performance of the PAFS, KAERI conducted two kinds of experimental program, i.e., PASCAL test facility and ATLAS-PAFS integral test facility. The PASCAL test facility used a single PCHX tube having the prototypic full-length scale with a volume scale of 1/240. On the while, ATLAS-PAFS test facility used three PCHX tubes with a-half length scale and a volume scale of 1/330 [2]. The various kinds of experimental results confirmed that the PAFS satisfies the cooling requirement and operational performances during the anticipated transient and accident conditions.

New experimental program with a large scale than the previous experiments have been recently launched in order to investigate an effect of scale ratio on the cooling performance and to observe more detailed boiling phenomena on the outside surface of PCHX tube bundles. The new experimental facility named LAPLACE (Large Scale PAFS Loop for Assessment of Condensation Effectiveness) is now being constructed. The volume scale of the LAPLACE test facility is 1/16 and the PCHX has 15 heat exchanger tubes of the prototypic dimensions.

In the present study, the major specifications of the LAPLACE test facility are described and some preliminary scoping analysis results using MARS-KS system analysis code are presented.

2. Description of the LAPLACE test facility

As shown in Fig. 1, the LAPLACE test facility is composed of a steam supply system, a steam supply line, PCHX, a return-water line, and the PCCT. Figures 2 and 3 show the isometric view of the LAPLACE test facility and the PCCT.

The LAPLACE test facility is designed according to a volume scaling methodology. Length and height scales in the test facility are preserved under the same pressure and temperature condition with the prototype.

By using electrical heater rods, the steam generator in the LAPLACE test facility provides saturated steam into the PCHX tubes. The water condensed in the PCHX tubes returns to the inlet plenum of the steam generator.

The LAPLACE test facility simulates 15 PCHX tubes with the prototypic geometry among 240 tubes in the APR+ power plants with the volume scaling ratio of 1/16.

The driving force of water level difference between steam supply system and the PCCT is maintained to be the same with that of the prototype in order to preserve the natural circulation flow.

Since ideally scaled-down water volume of the PCCT requires very large water tank at a high elevation (i.e., about 20 m from the ground surface), the water volume of the PCCT is reduced to about 1/48 of the prototype. A preliminary calculation showed that the scaling distortion of the PCCT water volume does not affect the boiling phenomena and only affect the total depletion time of the PCCT water. In addition, the small water volume affects only the later phase of the accident progression.

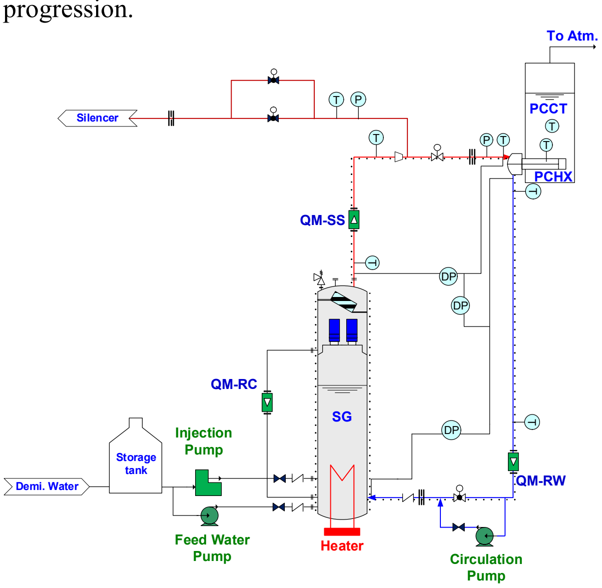

Fig. 1 Schematic diagram of LAPLACE test facility

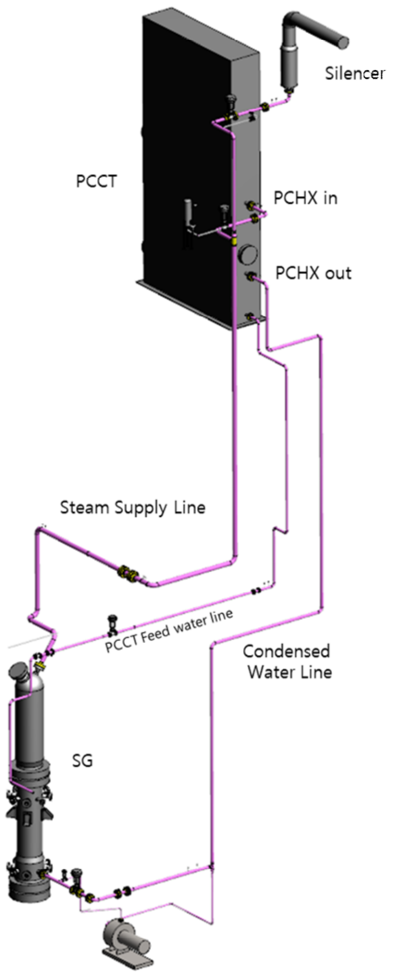

Fig. 2 Isometric view of the LAPLACE test facility

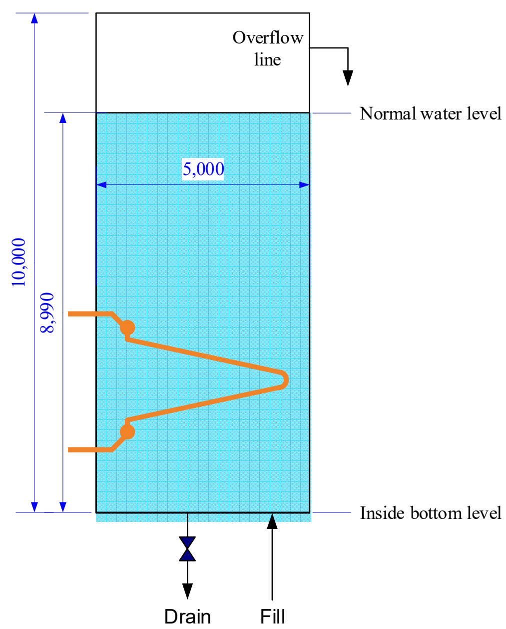

Fig. 3 Passive Condensation Cooling Tank (unit: mm)

3. MARS-KS Calculation for the LAPLACE test facility

The LAPLACE test facility was assessed with a thermal hydraulic analysis code, MARS-KS, to investigate the condensation heat transfer at the heat exchanger and the natural convection in the loop. The fluid system of the LAPLACE test facility as shown in Fig. 2 were modeled by one-dimensional components (SG, PCHX, steam supply line, condensed water line) or a three-dimensional component (PCCT). A test condition of the scaled full power with 8.1 MW was simulated in the calculation. Figure 4 shows the steam dome pressure with comparing to the calculation for the PASCAL test facility (A single tube PCHX with 1/240 scale). The steam pressure was increased until the condensation heat transfer was balanced to the heater power of the SG. It was converged under the design pressure of the PAFS operation, which means that the condensation heat transfer in the current PCHX design has a sufficient capability to remove the decay heat during an accident. Both of the calculation results for the LAPLACE and the PASCAL test facilities overestimated the steam pressure at the actual test result of PASCAL with a nominal thermal power (540 kW per a tube). It pointed out that the condensation model of the MARS-KS code showed a conservative prediction for the heat removal capability of the PAFS. A different behavior between the calculations of the LAPLACE and the PASCAL tests was attributed to the boiling heat transfer coefficient and the natural convection flow in the PCCT, which will be experimentally investigated in the LAPLACE test as a further study.

Natural convection flow observed in the MARS-KS calculation was compared in Fig. 5. The steam flow and the condensate water flow were equivalently balanced without any flow instability. A recirculation flow in the SG was maintained with a sufficiently higher value than the steam flow, so that the current design of the LAPLACE test facility can supply the steam flow with an enhanced heat transfer on the SG heaters.

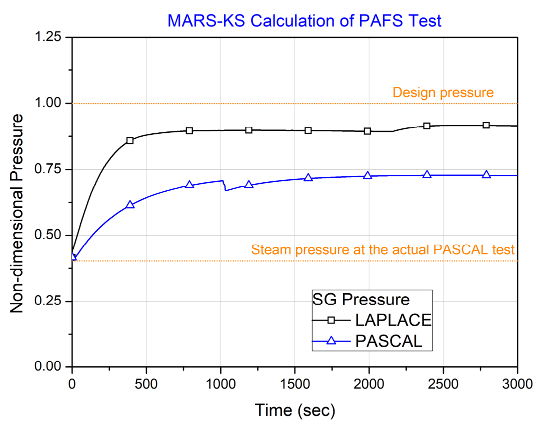

Fig. 4 Steam pressure in the MARS-KS calculation

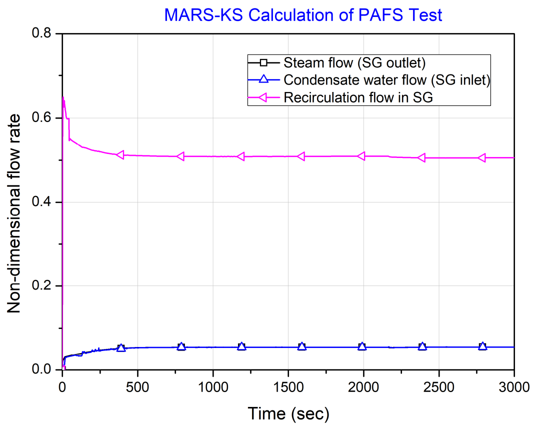

Fig. 5 Natural convection flow in the MARS-KS calculation

4. Conclusions

New experimental program with the volume scale of 1/16 for the PAFS of APR+ have been launched in order to investigate an effect of scale ratio on the cooling performance and to observe more detailed boiling phenomena during the anticipated transient and accident conditions. The LAPLACE test facility can be also used for the same kinds of experiments of the PAFS in APR1000 nuclear power plant which was developed for foreign export. The LAPLACE test facility is now being constructed for the new experimental program.

Major specifications of the LAPLACE test facility were described and some preliminary scoping analysis using MARS-KS system analysis code were presented. The scoping analysis shows that the current PCHX design has a sufficient cooling capability to remove the decay heat during an accident condition. The condensation model of the MARS-KS code showed a conservative prediction for the heat removal capability of the PAFS

ACKNOWLEDGEMENT

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