Preliminary Analysis of Mixing Tests in an Annular Vessel

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1. Introduction

KAERI has conducted a series of experiments to investigate the steam condensation and mixing phenomena in an APR1400 reactor [1]. Recently, thermal mixing tests were performed to study the characteristics of the mixing phenomena in an annular type vessel. Two types of accidents such as TLOFW and IOPOSRV were considered, and three different spargers were used to investigate the thermal mixing phenomena in the annular vessel and to provide test data for the development and verification of the thermal mixing models.

This paper presents a preliminary analysis of the mixing phenomena in an annular type vessel during a TLOFW accident.

2. Test Description

The mixing tests were conducted in the COMA (Condensation Induced Mixing in Annulus) facility at KAERI (Fig. 1) [2]. The test facility consisted of a steam boiler, an annular vessel, spargers, and piping and instruments. The annular vessel was a scaled-down model of the IRWST of the SKN 3,4 NPPs and the inside/outside diameters and the height of the annular vessel were 3.0/4.06 m, and 0.5 m, respectively.

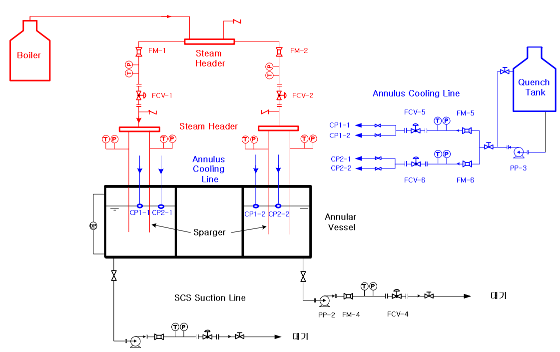

Fig. 1. Schematic Diagram of the COMA Facility

Total of 115 thermocouples (T/C) were installed at 25 T/C poles (Fig. 2) and each T/C pole contained 5 T/Cs at five different heights. In addition, two T/Cs were installed at the sumps for SCS (Shutdown Cooling System) suction lines (SC1 and SC2 in Fig. 2). At the important locations for the thermal mixing phenomena, the radial temperature distributions were also measured (A, B, G, H, and K T/C poles). Flow control valves and flow meters for the steam and water flows to and from the annulus were installed to control and measure the flow rates. In addition, two sight glasses were installed to observe the steam condensation and thermal mixing phenomena during the thermal mixing tests (Fig. 2).

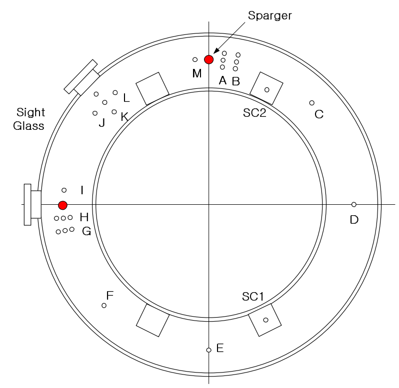

Fig. 2. Locations for the Temperature Measurement in the Annular Vessel

Fifteen tests were performed to investigate the thermal mixing phenomena in an IRWST (In-containment Refueling Water Storage Tank) during accidents. Three different spargers were manufactured according to the scaling law developed by KOPEC [2]. A type A sparger simulated 3 prototype spargers, a type B sparger simulated 6 spargers, and a type C sparger simulated a single sparger. Two types of accidents, TLOFW and IOPOSRV, were simulated using different spargers with the same test conditions. Operation of the SCS was also simulated in the specific tests.

3. Analysis of the Test Results

Test T01 simulated TFLOW in the SKN 3,4 NPPs. Two type B spargers were installed at 0 degree and 270 degree locations in the annulus as shown in Fig. 2 and the SCS operation was not simulated so that the fundamental thermal mixing phenomena due to the steam injection in an IRWST can be produced.

Figure 3 shows the vertical temperature differences between the local and the average temperatures at 200 s into the test. The water temperatures at the lower part of the T/C poles near the steam spargers (A, B, G, H, I, M T/C poles) were higher than those of the mid part. During the test, the hot jet induced by the steam condensation flowed vertically downwards. This hot jet impinged on the wall and bottom of the annulus and then the jet moved along the wall and the bottom of the annulus. However, the buoyancy force of the hot jet, eventually, changed the jet direction toward the surface of the water.

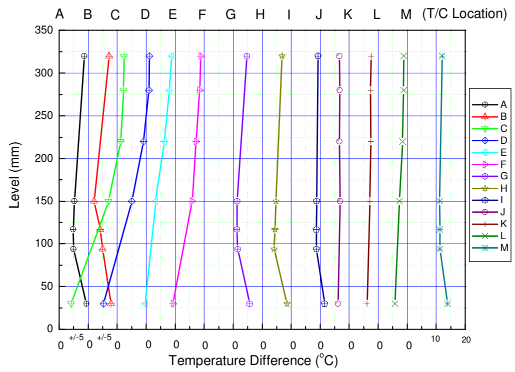

Fig. 3. Variation of the Temperature Difference at 200 s

Therefore, the hot jet from the sparger did not directly increase the water temperature at the lower part of the T/C poles which were located apart from the spargers. The water temperature at the lower part of the C T/C pole was much lower than that at the upper part as shown in Fig. 3 and the same phenomena were observed at remote locations such as the D, E, F T/C poles. However, the water temperatures at the lower section of the remote T/C poles were increased slowly by the natural circulation phenomena.

As the steam injection continued, a better thermal mixing occurred (Fig. 4) and the degree of the thermal stratification decreased near the spargers. However, for a remote location from the spargers, the degree of the thermal stratification is not small (up to 15 degree difference at the E T/C pole).

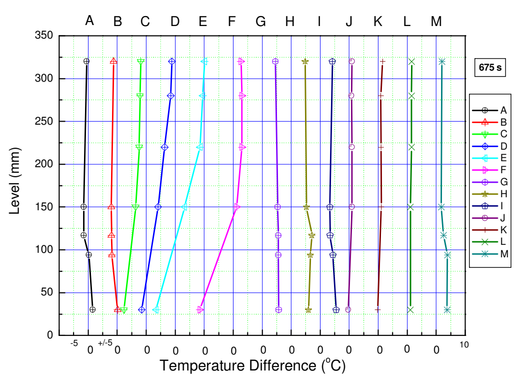

Fig. 4. Variation of the Temperature Difference at 675 s

Test T02 simulated the same accident as the test T01, but a SCS operation was performed. The test result shows that the operation of the SCS promoted the thermal mixing and the overall water temperatures with the SCS operation were much lower than those of the test case without the SCS operation as shown in Fig. 5.

At 600 s into the test, the water temperatures in the T02 test were at least 5 °C lower than those in the T01 test and for the higher temperature regions such as the G T/C pole the temperature difference reached up to 15 °C. Especially, a large temperature difference near a sparger (H T/C pole) is very important for the safety of the plant as a low water temperature near a sparger can postpone the occurrence of unstable condensation phenomena in a pool [3].

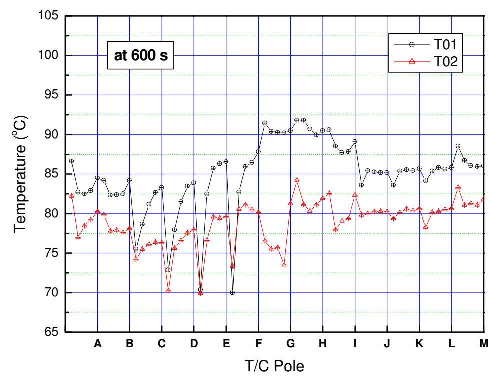

Fig. 5. Variation of the Temperature Difference at 600 s in Two Different Tests

4. Conclusions

A series of thermal mixing tests were performed to investigate the thermal mixing phenomena in an annular type vessel. It is concluded that the test results provided detailed information of the temperature distribution in an annular vessel and that the test data can be used to develop and validate a thermal mixing model. The test results also show that the operation of the SCS is valuable to slow down the increase of the water temperature during an accident.

ACKNOWLEDGMENTS

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