Thermal Mixing Phenomena due to a Steam Injection into a Cylindrical Tank

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1. Introduction

Experimental program for a thermal hydraulic evaluation or verification of new design features in the APR1400 has been in progress for selected items at the Korea Atomic Energy Research Institute (KAERI) [1]. To establish more reliable data for thermal mixing phenomena, a series of thermal mixing tests was performed. This paper presents the results of the repetitive thermal mixing experiments using a multi-hole sparger.

2. Test Description

The mixing tests were conducted using the B&C test facility at KAERI [2]. The test facility consists of a steam boiler, two flow control valves, two vortex flow meters, spargers, a quench tank, and piping and instruments. The boiler can supply saturated steam (1.0 MPa) at a maximum rate of 0.4 kg/s. And the diameter and the height of a cylindrical tank (quench tank) were 3 m and 4 m, respectively.

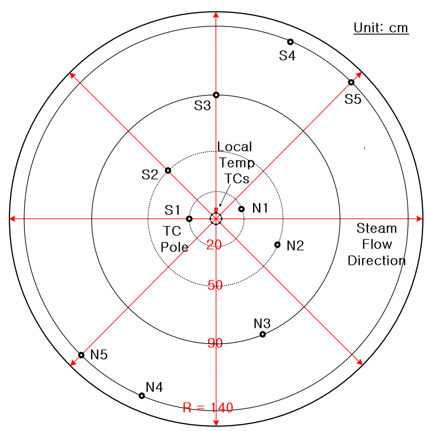

Fig. 1. Distribution of the TC poles in the quench tank

Sparger had 16 horizontal discharge holes (5 mm ID, 2 rows and 8 holes per row). A series of repetitive thermal tests was established to define the standard thermal mixing phenomena. Nine thermal mixing tests with the same initial test conditions (600 kg/m^2-s and 40 ^{o}C water temperature) were performed.

In the quench tank, 166 thermocouples (TC) were installed to measure the water temperature during a test. Ten TC poles (S1~S5, and N1~N5) were installed (Fig. 1) and each TC pole contained 13 thermocouples to measure the vertical water temperature distribution at the TC pole location in the quench tank. To measure the local water temperature distribution, 36 TCs were installed near the horizontal steam discharge holes.

3. Test Results and Discussions

3.1 Mean Temperature

To define a typical temperature variation during a test, the initial water temperatures were set to an equal temperature (40 ^{o}C) and the valve opening times were adjusted to open at the same time for the 9 tests. Then all the adjusted temperature data from the 9 tests for each location were gathered as a function of time and sorted sequentially. A typical water temperature (mean temperature) was obtained by using the adjacent averaging method.

Independent thermal mixing test data for the same initial conditions were used to validate the developed mean temperatures. Figure 2 compares the variations of the water temperature at the S1-05 location. The temperature data at the S1-05 location in the test are similar to the developed mean temperature data, and most of the deviation of the test data from the mean temperature data is within one standard deviation.

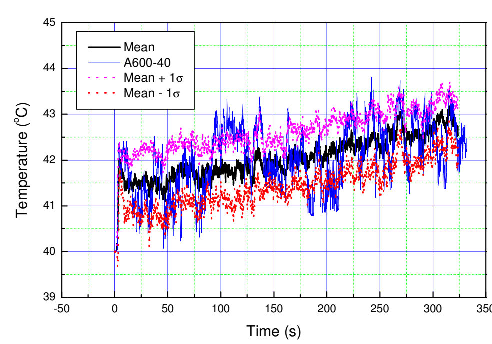

Fig. 2. Comparison of the mean temperature and the test data for the S1-05 location

The agreement between the mean temperature and the measured temperature data becomes better for the farther locations from the horizontal steam discharge holes. Figure 3 compares the mean temperatures developed in this study to the independent test data for the S1-03 locations. As seen in the figures, the mean temperatures are in good agreement with these test data. It is concluded that the mean temperatures developed by this statistical method are meaningful and they can be used for the development and verification of a thermal mixing model.

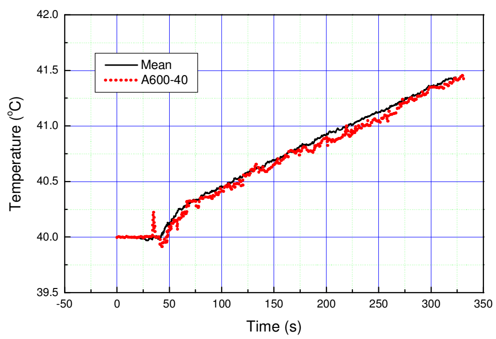

Fig. 3. Comparison of the mean temperature and the test data for the S1-03 location

3.2 Mixing Phenomena

Test results show that the steam was condensed very shortly after its injection into the water pool and a hot liquid jet moved horizontally towards the tank wall. In general, when a liquid jet hits a vertical wall, it will usually expand into a radial jet moving out along the wall in all directions. However, the test results show that much of the hot jet moved into a lower part of the quench tank. A minor part of the wall impingement moved upwards along the wall. The water then either moved along the wall up to the surface of the water or crossed the upper part of the quench tank to the center of the quench tank (Fig. 4).

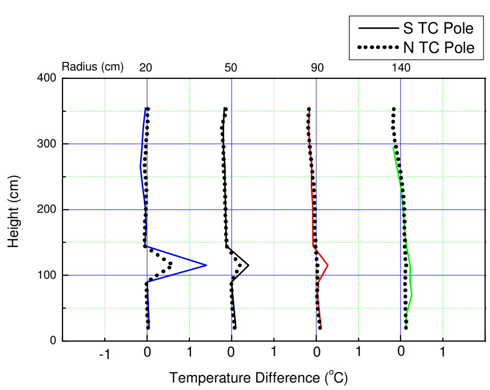

Fig. 4. Vertical pool temperature distribution at 175 s (S and N series TC poles)

The test results also show that the local water temperatures very near the discharge holes were not much higher than the average pool temperature. Figure 5 shows the temperature differences between the local and the average pool temperatures. Steam discharge holes located at 115.0 cm and 117.5 cm from the bottom of the quench tank, respectively. The horizontal distances from the center of the steam core to the A5 and A7 TC Poles at these elevations were 5.1 and 10.0 mm, respectively, and they were 5 mm apart from the surface of the sparger. However, the temperature differences at these locations were less than 0.6 °C.

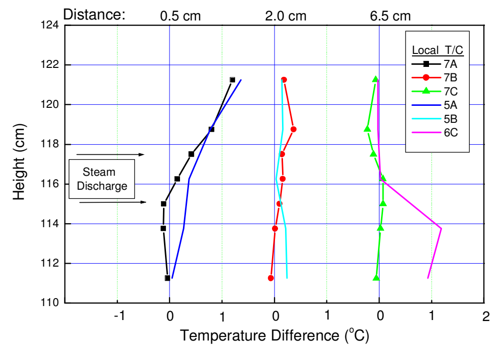

Fig. 5. Temperature Differences at the Local Spots near the Steam Discharge Holes

4. Conclusions

A series of thermal mixing tests were performed to investigate the thermal mixing phenomena due to the injection of steam into a cylindrical tank. The test results show that a thermal mixing occurred evenly in a cylindrical tank. Typical water temperature distribution for the initial conditions of a 600 kg/m^2-s steam mass flux and a 40 °C water temperature in a cylindrical tank were developed using nine repetitive mixing test data and it was concluded that the developed temperature data can be used to develop and validate a thermal mixing model.

ACKNOWLEDGMENTS

This paper has been prepared based on R&D work sponsored by KOPEC.

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