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Experimental Investigation of the Local Temperature Distribution and Thermal Mixing Phenomena in a Cylindrical Tank

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1. Introduction

KAERI has performed a series of steam condensation tests to assess the performance of a unit cell sparger that will be used in the APR1400 reactor. Unit cell sparger (I-type sparger) and simplified I-type sparger were used for the steam condensation tests to study the characteristics of the condensation phenomena due to multi-hole spargers. And the major test parameters were the steam mass flow rate and water temperature in the tank.

This paper presents an overview of the local temperature distribution near the sparger discharge holes and the thermal mixing phenomena induced by a steam discharge and condensation in a cylindrical tank.

2. Overview of the Steam Condensation Test Program

The condensation test program consists of steady state and transient steam condensation tests in a cylindrical tank. Simplified I-type spargers were used for the steady state condensation tests. Saturated steam was discharged into the tank through a sparger and the dynamic pressure and temperature of the water in the tank were measured.

The condensation tests were conducted at the B&C test facility [1] at KAERI. The test facility consisted of a pressurizer, a flow control valve, a venturi flow meter, spargers, and piping and instruments (Figure 1).

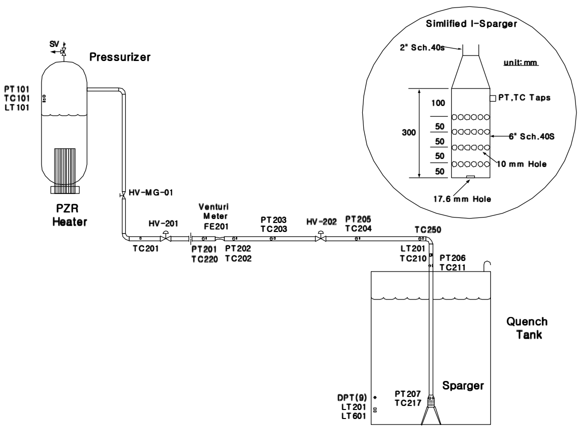

Figure 1. Schematic Diagram of the B&C Loop

The volume of the pressurizer is 0.85 m^3. The main piping consisted of 2" Schedule 160 pipe and it is connected to the pressurizer and the quench tank. A sparger was installed in the middle of the quench tank. A flow control valve controlled the steam flow rate through a sparger during the steady state tests. A venturi flow meter was used to measure the volumetric steam flow rates, and several pressure and temperatures sensors were installed in the main piping system.

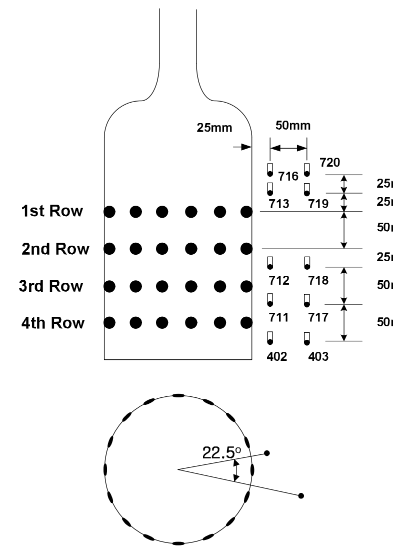

Figure 2. Location of the Thermocouples for the Local Temperature Distribution

In the quench tank, 64 thermocouples were installed to measure the water temperature during the tests [2]. Ten thermocouples were dedicated to measure the water temperature near the steam discharge holes (Figure 2) and 54 thermocouples were used to measure the thermal mixing phenomena in the tank.

3. Analysis of the Test Results and Discussion

The local temperature is defined as the fluid temperature in the vicinity of a discharge device [3] during a steam discharge and it represents the relevant temperature which controls a condensation process. For a practical purpose, the average temperature observed within the region subtended by the quencher arms at the same elevation as the quencher device can be considered as the local temperature. However, the quenching device such as the unit cell sparger does not have an arm (I-type sparger) and therefore, the definition mentioned above can not be used.

Experimental data indicates that the local temperatures were dependent on the steam mass flux and water temperature. Figure 3 shows the temperature difference between the local and bulk temperatures very near the discharge holes for the 40 ^{o}C water temperature condition. The temperature between the 2nd and 3rd row of holes (TC712) was the highest of all the other locations, and the temperature below the 4th row of holes (TC402) was the lowest for the low steam mass flow rate (less than 1.6 kg/s). In addition, the temperature at the top portion of the first row of holes (TC713) is comparable to that between the 3rd and 4th row of holes (TC711).

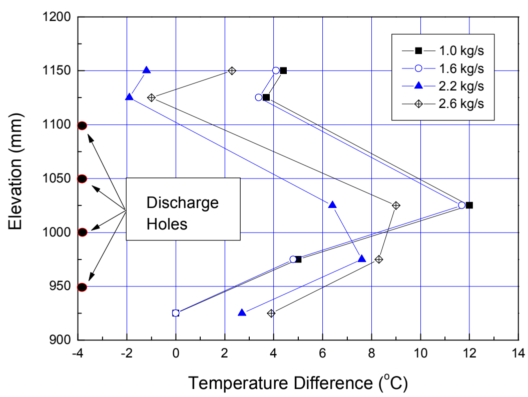

Figure 3. Local to Bulk Temperature Difference for the 40 ^{o}C Condition

However, for the higher steam mass flow rate conditions, the temperature at TC711 was higher than that at TC712 and the temperature at TC402 was higher than that at TC713. These phenomena seem to be caused by a balance between the buoyancy and the inertia of the jet and by an entrainment of water into the jet.

According to previous works, the steam is condensed over a very short distance (0.4-1.5 times the discharge hole diameter) so we can consider the flow as a liquid jet at 25 *mm* downstream of the discharge hole. For the low and mid mass flow rate conditions, the jet shows a transition to a buoyant behavior at a short distance from the discharge point and a buoyant upflow increases the water temperature at TC712 more rapidly than that at TC711.

In the case of a higher mass flow rate condition, the transition to a buoyant behavior occurs at a long distance from the discharge point with a very little upward motion due to a buoyancy effect. In addition, the impingement of a liquid jet induces a downward flow of the hot water and it results in a hotter temperature at TC402.

Thermal mixing is also affected by the same mechanism mention above. For the high mass flow rate conditions, the water temperatures near the tank wall are hotter than those at the center of the tank as seen in Figure 4. But, the temperatures at the center of the tank are always higher than those at the wall for the low flow rate condition. The impingement of a jet and the entrainment of water into the jets greatly affect the thermal mixing phenomena in a tank.

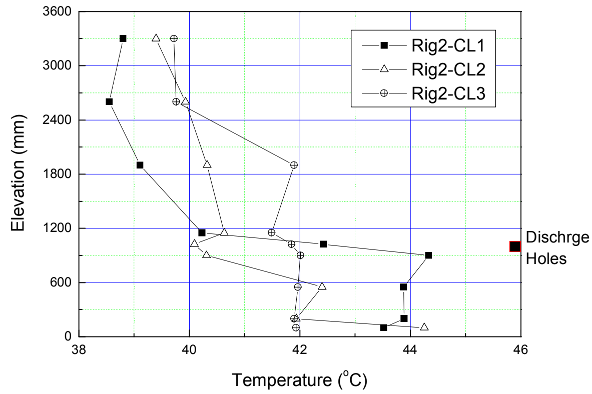

Figure 4. Water Temperature Distribution for the 40 ^{o}C, 2.2 *kg/s* Flow Rate Condition

4. Conclusions

A series of steam condensation tests have been performed and water temperatures were measured to investigate the local temperature distribution and thermal mixing phenomena during a steam condensation process in a tank. The maximum local to bulk temperatures reached 12 ^{o}C and the steam mass flow rate through a discharge hole was considered to be a major parameter for the resultant local temperature distribution. Thermal mixing phenomena are also affected by the steam mass flow rate.

ACKNOWLEDGMENTS

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