# Thermal Mixing in Water Pool under Steam-Discharging Condition

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## 1. INTRODUCTION

The In-containment Refueling Water Storage Tank (IRWST) of Advanced Power Reactor-1400 (APR-1400) design, during accident condition, condenses the steam discharged from the safety valve through the steam relief device, the sparger which has a lot of holes to discharge high-temperature steam, effectively. One of the key issues in the design of IRWST and sparger was to avoid the undesired unstable condensation which may be a challenge to structural integrity of the piping system and tank. Unstable condensation was known to start at the local pool temperature above 200°F depending on the steam mass flux through the hole and the configuration of the sparger. Therefore, the maximum local temperature during the accident was limited to 200°F to saturation temperature in the Suppression Pool of Boiling Water Reactor (BWR) design [1]. The criterion also has been adopted in the APR-1400 design, since the IRWST has the same function and thermal-hydraulic behavior.

The local temperature in the water pool may be a function of the interfacial condensation heat transfer and the flow field induced by the steam jet from the sparger holes. Generally, determination of the local temperature requires three-dimensional hydrodynamic calculation with two-phase steam jet, condensation, turbulent mixing, etc. Recent advances in Computational Fluid Dynamic (CFD) codes enable the calculation of the IRWST flow field, however, two-phase flow prediction still has been a difficult area in the most CFD approaches. Meanwhile, the applicability of system thermal-hydraulic codes such as RELAP5 and TRAC has not been fully discussed because of their limitation of 3-D capability and/or lack of turbulent modeling capability although those codes were known to have practical and well-qualified two-phase constitutive models.

The present paper aims to discuss the applicability of the TRACE code[2] to the prediction of this kind of thermal mixing problem. The TRACE code, as a successor of the TRAC code, has a capability of 3-D hydrodynamics in vessel. To assure the applicability, two experiments[3] conducted in B&C Loop in Korea Atomic Energy Research Institute (KAERI) were calculated using TRACE code in the present paper. The test was believed a scaled representation of the actual IRWST.

## 2. EXPERIMENTS AND TRACE MODELING

The experimental facility (B&C Mod-B) was consisted of a pressurizer, a quench tank equipped with various instruments, connecting pipe and valves. The quench tank was 4 m in height and 3 m in diameter. Single I-type sparger with inner diameter of 0.164 m was installed at the center of the quench tank, which is the prototype one of APR-1400. It is a cylindrical pipe in which load reduction ring, several radial holes and one axial hole were perforated. The initial water level was 3.5 m from the bottom of the tank and the end of the sparger was 0.9 m above the bottom [3].

The tests TR-10 and TR-14 were selected for the TRACE simulation. The initial pressure in the pressurizer was 15.8 MPa and the range of steam flux was 100~750 $kg/m^2$-s for both tests. Pool water temperature was initially 20°C and 90°C for TR-10 and TR-14, respectively. In experiment, steam discharge was initiated by opening a valve at 2 seconds.

The TRACE Version 4.05 was used, which has been improved from the previous TRAC code. Especially, Chen and Mayinger interfacial condensation heat transfer model for bubbly and slug flow regimes was used [2].

The TRACE model of the test facility was shown in Fig. 1. The components “fill” and “break” was used to simulate the experimental boundary condition. A “tee” and a “vessel” components were used for the sparger and quench tank, respectively. The vessel has 14 axial levels and 5 radial rings and one azimuthal sector. The load reduction ring of the sparger pipe was modeled minor flow path from the side volume of tee to the vessel. The flow area at the cell (5,1,1) was restricted to match the total area of sparger holes. An appropriate K-factor was assigned at each junction from the fill to the vessel.

In the code run, 100 seconds steady calculations were conducted before transient and then 40 seconds transient calculation were continued. The maximum time step size was 0.01 seconds for both runs..

## 3. RESULT AND DISCUSSION

Result from the transient calculation of test TR-14 was provided in Figures 2 and 3. Figure 2 shows comparisons of fluid temperature at 3 elevations in the mid-location between sparger and tank wall.

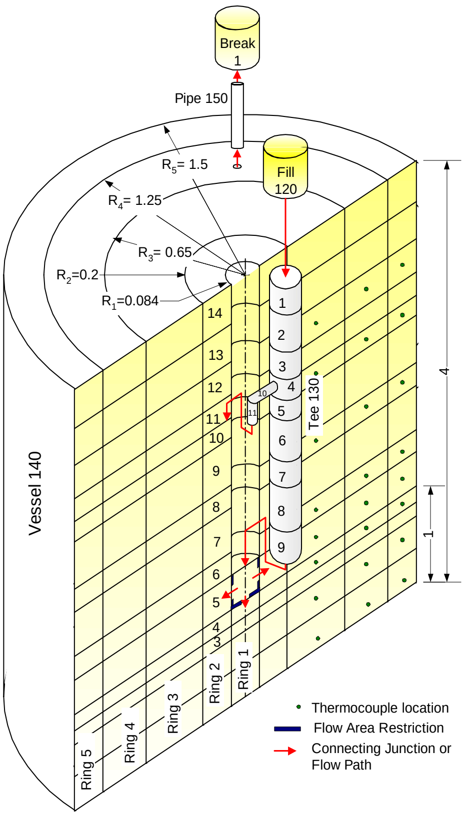


Figure 1 TRACE Model for Thermal Mixing Test

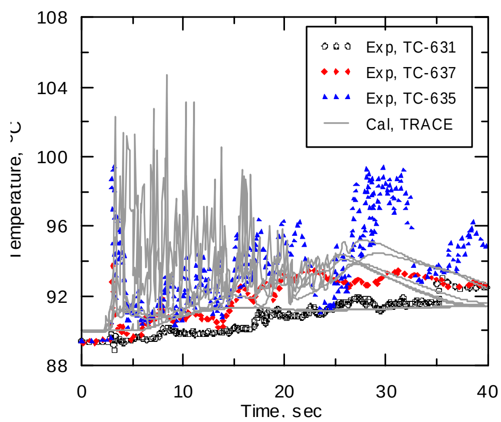


Figure 2 Comparison of Fluid Temperature

The calculated behavior was well agreed to the measured data except after 25 seconds. The oscillation in the calculation during early 20 seconds was due to the violent condensation with high-frequency, which indicated disappearance and appearance of liquid in those cells. Deviation after 25 seconds may due to mismatch of incoming steam flow rate. After incoming steam mass flow rate decreased, such an oscillation was disappeared,

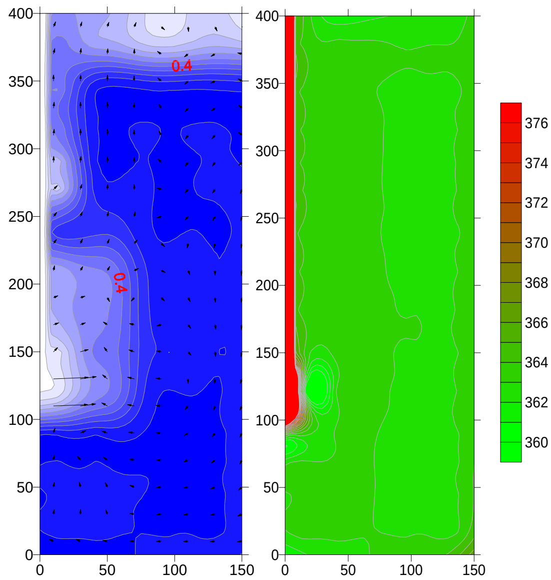


Figure 3 Void Fraction and Temperature Contour at 3 seconds

which mean the condensation region was reduced to the very-near area of the sparger pipe.

Figure 3 shows contours of void fraction and liquid temperature at 3 seconds. Liquid velocity vector was also plotted in the same figure. One can guess that flow field was established by the liquid entrainment by the discharged steam and buoyancy force and that. Local temperature and void distribution also were established consistently with the flow field.

## 4. CONCLUDING REMARKS

To discuss the applicability of the TRACE code to thermal mixing prediction in a tank with steam discharged, two KAERI tests were calculated using the TRACE code. As a result, the predicted local temperature behavior was quite well agreed with the measured data and the flow field and void/temperature distribution was reasonably predicted. Based on those findings, one can conclude that the TRACE code can be applied to the discussion of the local temperature behavior in the IRWST of the APR-1400.

## REFERENCES

[1] USNRC, *Suppression Pool Temperature Limits for BWR Containments*, NUREG-0783, November 1981

[2] USNRC, *TRACE V.4.0 Users Manuals*, Oct. 2002.

[3] Y.S. Kim et al., “Experimental Study of Thermal Mixing of Steam Jet Condensation through an I-Sparger in a Quench Tank,” *Energy Engg. J*, Vol.14, No.1, pp. 62-71, 2005.