IRWST Water Temperature Distribution Analysis during POSRV Actuation

I. S. Yeo [a*], Y. T. Moon[a], K.K. Woo[a]
[a]*Korea Power Engineering Co., Inc, 360-9 Mabuk-Dong, Giheung-Gu, Yonin-Si, Gyeonggi-Do, 446-713, Korea.*
[*]*Corresponding author: isyeo@kopec.co.kr*

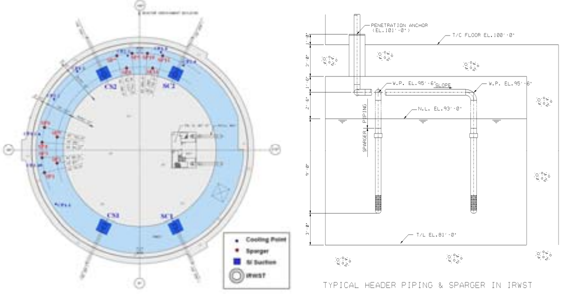
1. Introduction

Continued steam blowdown into the pool will increase the local pool temperature. The condensation rates at the turbulent steam/water interface are eventually reduced to levels below those needed to readily condense the discharged steam. At this threshold level, the condensation process may become unstable; for example, steam bubbles may be formed and shed from the pipe exit, and the bubbles oscillate and collapse, which may give rise to severe pressure oscillations which are imposed on the pool boundaries.

In this paper, the detail IRWST water temperature during the postulated Inadvertent Opening of POSRV is analyzed using CFX code. An optimized 3-D evaluation methodology, which is developed to evaluate the expected thermal hydraulic behavior of the IRWST, is applied to SKN 3&4 IRWST water temperature analysis [1]. This methodology was verified and validated by the comparison of CFX analysis with results of experiment.

2. Design features related to IRWST in SKN 3&4

In SKN 3&4 the major systems and components related to IRWST are pressurizer Pilot Operated Safety Relief Valves (POSRVs), Safety Depressurization and Vent System (SDVS), In-Containment Water Storage System (IWSS), Shutdown Cooling System, Safety Injection System, and Containment Spray System [2]. Overpressure protection for the RCS is provided by means of POSRVs and Reactor Protection System (RPS) in accordance with the requirements. The SDVS piping transports the POSRV discharge from the pressurizer to the IRWST. The IRWST provides storage of borated water for refueling, for injection into the RCS by the SIS, for the CSS, as a supply for cavity flooding and for quenching SDVS discharges. The IRWST has the floor area of 7,371 ft^2. Overall tank height is 16.0 feet and normal water level is 12 feet from tank bottom as shown in Fig. 1.



(a) Plan view (b) Section view
Fig. 1. SKN 3&4 IRWST

3. IRWST water temperature analysis

The state-of-the arts of computational techniques are still immature to provide the reasonable results for the direct contact condensation (DCC) of steam jet in subcooled water pool. It is assumed that the discharged steam into the subcooled water pool is condensed over a short distance.

3.1. Event for IRWST design

From the viewpoint of IRWST pool temperature, IOPOSRV is a limiting case of DBEs. Following the initiation of IOPOSRV, the pressurizer pressure is slowly decreased to the closing setpoint of the POSRV isolation valve which is located in series and downstream of the POSRV. The automatic closing of the POSRV isolation valve terminates the transient and stabilizes the RCS pressure. Reactor trip will not occur because the POSRV isolation valve closing setpoint is established to avoid a reactor trip. After 30 minutes, the operator manually trips the plant and cools down to the shutdown cooling entry condition.

3.2. Local pool temperature

From the viewpoint of unstable condensation, we can consider a local hot spot, which may exist due to an unfavorable thermal mixing in a large pool and resultantly affect the stability of condensation. The local pool temperature is defined as the fluid temperature in the vicinity of the sparger during steam discharge and represents the relevant temperature which controls the condensation process occurring at the sparger exit. In general, this is different from both the temperature of the water in contact with the steam and from the bulk pool temperature. Based on this definition, the temperature which controls the condensation process (that is, the "local" temperature) is best characterized by that which would occurs at a point above and below the steam condensation region boundary.

3.3. Numerical Simulation

Steam condensation region model is used to evaluate the temperature in IRWST, which has been developed based on the water temperature data around a steam jet to simulate the DCC. In this model, only the calculated velocity of the condensed water is used as the boundary condition for CFD analysis. In addition, the energy of discharged steam is used directly as energy of steam condensation region.

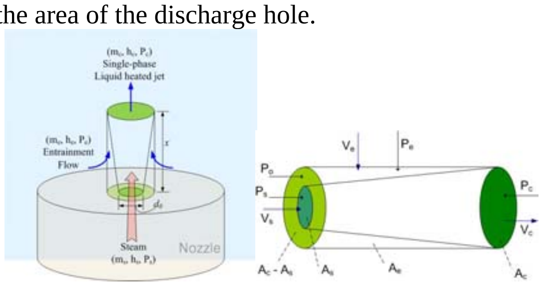
The boundary conditions at steam condensation region boundary are found from the conservation of mass, momentum and energy equations, Eqs. (1)-(3).

$$\dot{m}_s + \dot{m}_e = \dot{m}_c \quad (1)$$

$$\rho_s V_s^2 A_s + P_s A_s + P_\infty (A_c - A_s) = P_c A_c + \rho_c V_c^2 A_c \quad (2)$$

$$\dot{m}_s h_s + \dot{m}_e h_e = \dot{m}_c h_c \quad (3)$$

As shown in Fig. 2, in above equations, $\dot{m}_s$, $\dot{m}_c$ and $\dot{m}_e$ represent the steam, the condensed, and the entrained mass flow rate, respectively. P_s represents the pressure of the steam leaving the discharge hole, and A_s is the area of the discharge hole.



(a) Nozzle exit (b) CV of lumped jet region

Fig. 2 Steam condensation region model

The the static pressure of the ambient water, P_∞, in the tank is determined as follows:

$$P_\infty = P_{amb} + \rho_e g h \quad (4)$$

In CFX code, it is possible to simulate the steam condensation region as a subdomain. A subdomain is a 3D region within a predefined domain that can be used to specify values for volumetric sources of energy, mass, momentum, radiation and others. Therefore, the condensed water velocity and the energy of discharged steam are used as inputs of subdomain. With these values, the thermal mixing induced by steam jet in IRWST is calculated by using an SST turbulent model and some other physical models.

3.4. Grid model and boundary conditions

The geometry and grid model for SKN 3&4 IRWST are generated by considering 12 spargers and 4 suctions. Fig. 3 shows the geometry around the steam condensation region. For a sparger, there are three parts of steam condensation region, i.e., side hole, LRR, and bottom hole region.

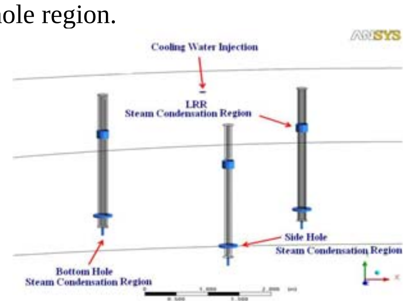


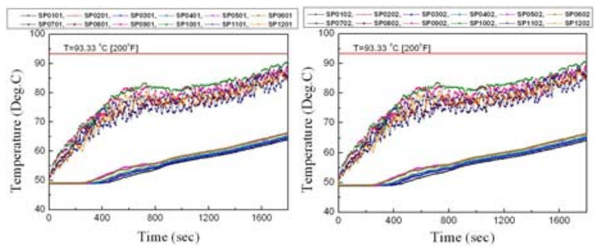
Fig. 3 Sparger geometry

The meshes are more densely distributed near the condensation region and water discharge and suction locations. These fine meshes make it possible to accommodate the high velocity and temperature gradients. A total of 1,518,573 nodes were generated by ICEM codes. Transient simulations were carried out with a time step size of 1~2 s with convergence criteria that the residue falls below 10^{-4}. A coupled solver of CFX was used to solve all the governing equations. High resolution discretization scheme was used for mass and momentum equations, turbulent kinetic energy and turbulent dissipation rate. The discretized equations were solved using the Tri-Diagonal Matrix Algorithm (TDMA). Data points at various locations were tracked in order to observe the temperature variation.

4. Results and discussion

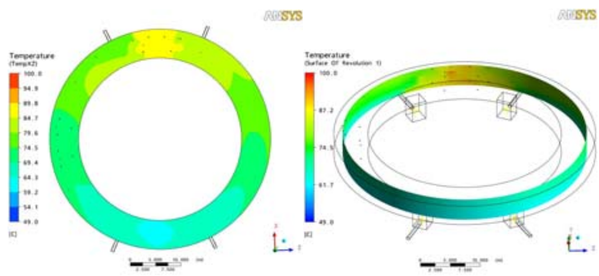
The local IRWST pool temperatures at the location of 5cm and 10cm above steam condensation region, are shown in Fig. 4. Steam and steam/water mixture are discharged from sparger through 07 to 12 which are located at 180 degree area of IRWST. Therefore, it shows clearly the difference between the discharging spargers and other spargers. The overall temperature distributions in IRWST are shown in Fig. 5.

From these results, it is concluded that the local temperature is less than 200 ^{o}F during IOPOSRV. Thus the intermittent condensation condition is not occurred for design basis events.



(a) 5cm above (b) 10cm above

Fig. 4. IRWST local temperature



(a) Top plan (b) Vertical plan

Fig. 5. Temperature profiles at the end of calculation

REFERENCES

[1] KOPEC, "Optimized 3-D Evaluation of IRWST Thermal Hydraulic Behavior", R-2005-A045, 2008

[2] KOPEC, "IRWST T/H Transient Analysis Report", 2008