CFD Analysis of Steam Jet Condensation through the Nozzles in a Subcooled Water Tank

Seong Dae Park*, Jinhwa Yang, Hyun Sik Park
Korea Atomic Energy Research Institute, Daejeon, Republic of Korea
**Corresponding author: sdpark@kaeri.re.kr*

1. Introduction

Sparging of condensable into liquids is carried out carried out in the process industry for direct contact mass and heat transfer. Because of the high heat transfer rates and condensation occurring at the interface, the flow near the interface is turbulent. Some researches were conducted to observe and understand the phenomena [1, 2 and 3].

System-integrated Modular Advanced ReacTor (SMART) is a Small Modular Reactor (SMR) developed by Korea Atomic Energy Research Institute (KAERI) [4]. SMART IRWST Separated Test Apparatus (SISTA) was installed in SMART-ITL to evaluate the Passive Containment Cooling System (PCCS). PCCS can lower the pressure and temperature of containment during accident and prevent the release of radioactive material to atmosphere by condensing steam and dissolving radioactivity into an In-containment Refueling Water Storage Tank (IRWST).

In this work, a preliminary analysis were performed to set the condensation model in order to confirm the mixing effects caused by the condensation phenomenon. Thermal-hydraulic analysis was performed with a conventional CFD code, ANSYS-CFX.

2. Computational model

A two-phase model has been formulated in the Euler–Euler framework using the method of interpenetrating continua. Water has been considered as the primary phase, with the steam as the secondary phase. Inter-phase mass transfer has been tracked by using the thermal phase-change model. For turbulence closure, k-e model have been incorporated.

A thermal phase change model has been used to simulate evaporation and condensation phenomena, which describes the phase change induced by interphase heat transfer of intrinsic flows. It is only applicable to a change of phase in pure substances and considers the heat transfer processes on each side of the phase interface. Hence, the two-resistance model for interphase heat transfer has been used. The sensible heat flux was given by

$$q_f = h_f(T_s - T_f) \qquad (1)$$

$$q_g = h_g(T_s - T_g) \qquad (2)$$

Where h_f and h_g are the heat transfer coefficients for fluid and gas phase, respectively. The heat transfer coefficient (h_g) across interface and gas phase was modeled by using zero equation model. In this model, it is assumed that the amount of heat generated is completely transferred across the interface. Thus heat transfer was calculated by simple heat balance. The heat transfer coefficient (h_f) across interface and liquid phase was modeled using Ranz Marshal model.

$$Nu = 2 + 0.6 \mathrm{Re}^{0.6} \mathrm{Pr}^{0.3} \qquad (3)$$

T_s is the interfacial temperature determined from considerations of thermos dynamic equilibrium and it is assumed to be the same (saturation temperature) for both phases. The interphase mass transfer is determined from the total heat balance. Total heat flux balance is given in Eqs.(4) and (5),respectively.

$$Q_g = q_g - \dot{m}_{gf} H_{gs} \qquad (4)$$

$$Q_f = q_f - \dot{m}_{gf} H_{fs} \qquad (5)$$

Here m_{gf} denotes mass flux into liquid phase from gas phase and H_{gs} and H_{fs} represent interfacial values of enthalpy carried into and out of the phases due to phase change. The total heat balance determines the inter-phase mass flux (6) as follows:

$$\dot{m}_{gf} = \frac{q_f + q_g}{H_{gs} - H_{fs}} \qquad (6)$$

3. Thermal Hydraulic Analysis

3.1 Geometry model & boundary

The geometry models was described in Fig. 1. The figure of the left side is the geometry of the SISTA facility. The simplified geometry for the water tank and the specific sparger is shown in the right side. The specific sparger is different from the geometry of the general sparger. The individual nozzle is attached in the hole, respectively. The following design is considered to limit the mutual influence of injected vapor from the nozzles.

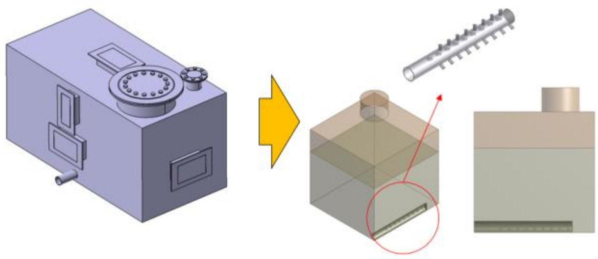

Fig. 1. Geometry of water tank and sparger

The boundary condition of the models is described in the Fig. 2. The initial condition of the air and the water is set with 1 bar pressure and 50 °C temperature. The inlet and outlet of the tank is set as the opening wall condition to naturally induce the vapor injection and allow the air in and out through the outlet.

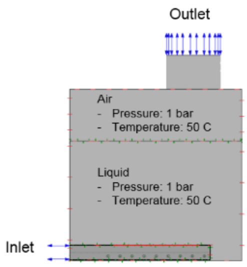

Fig. 2. Boundary condition in models

3.2 Pressure effect

The vapor behavior due to the condensation was described in the Fig. 3. The vapor is immediately condensed at the end of nozzle. The momentum coming out from hole of the nozzle with the vapor is transmitted to the surface of the water, so that the surface of the water is fluctuating.

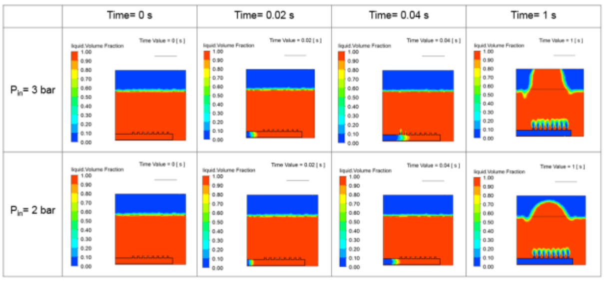

Fig. 3. Behavior of the vapor

3.3 Heat transfer

The trend of the heat transfer near the sparger was shown in Fig. 4. The vapor is strongly injected through the nozzles. The water is circulated and the heat is transferred.

The flow vectors near the nozzle were shown in Fig. 5. The mixing of the water is actively performed due the vapor injection and the condensation. The heat transfer takes place in the tank by such mixing effect.

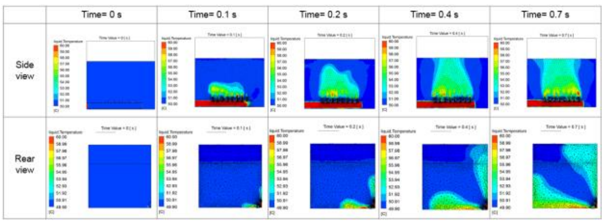

Fig. 4. Heat transfer near the nozzle

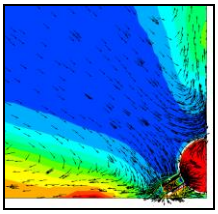

Fig. 5. Vector near the nozzle

4. Further work

The thermal hydraulic analysis for the condensation in the SISTA facility was performed. It is confirmed that the condensation phenamenon is simulated with the set of the model and the boundary condition. The anlysis will be peroformed with the real boundary condition reflecting the accident scenarios.

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