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Numerical Study on Direct Contact Condensation Phenomenon of Saturated Steam

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1. Introduction

The condensation of steam is a common engineering phenomenon influencing many technological and industrial applications. The condensation phenomenon is very important in the design of systems with a phase change from steam to water.

A Direct Contact Condensation (DCC) of steam at low mass flux and the pressure oscillation induced by steam condensation was investigated and analyzed. Simulations using lumped-parameter codes have been considered as one option to model suppression pools [1]. Pttikangas et al. [2,3] simulated the water hammer due to a steam bubble collapse by using 2D-axisymmetric CFD (Computational Fluid Dynamics). Yadigaroglu and Lakehal [4] suggested that the Volume Of Fluid methodology (VOF) simulation for the injection of steam/air-mixture from a vertical blowdown pipe into a water pool can exchange the rates for the DCC heat and mass transfer.

This study is to evaluate condensation phenomena using the VOF methodology with condensation physics continuum and conjugated heat transfer in the chugging flow region.

2. Methods and Results

The DCC occurs when vapor is brought into contact on the surface of a liquid. The DCC calculations are usually related to either liquid single-component or two-phase (steam-water) systems for liquid portion, and either pure steam or steam including noncondensable gas (air) for gas portion.

2.1 Computational model

CFD simulation was performed using the commercial code, STAR-CCM+ [5]. Also, a grid with about 3 million cells is generated and the polyhedral mesh was chosen to increase computational accuracy for conjugated heat transfer.

Fig. 1 shows that the suppression pool is composed of the steam flow inlet, flow(pressure) outlet, perforated blowdown pipe and main structure body. The blowdown pipe has a small hole at the top in the suppression pool and a lot of holes at the bottom for condensing steam.

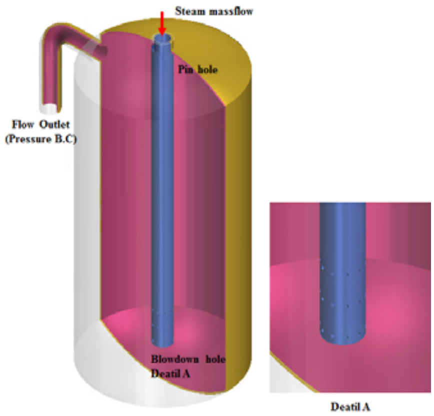

Fig. 1. Configuration of suppression pool

The initial water level inside the suppression pool is 30% above the bottom of the suppression pool. The external environmental condition is assumed to be the atmosphere at a constant temperature of 48.9 °C and the suppression pool wall has a heat transfer coefficient of 10 W/m^2-K.

Table I: Models for physics continuum

Conditions	Parameters
Operation pressure	Atmospheric condition
Multi-component	Gas: ideal gas (staem, air) Liquid: water
Volume Of Fluid - Saturation Pressure: User function (interpolate table) - Evaporation/Condensation model	
Steam mass flow	0.468 kg/m^{2}s @sat. temp.
Flow(Pressure) outlet	0 Pa (Gauge)
Turbulent model	RANS k-w SST model
Initial pressure	Hydrostatic pressure (water)
Initial temperature	48.9 °C
Initial mass fraction	air: 0.99 / vapor: 0.01 water: 1.0 (water region)

Table 1 shows the multiphase flow input conditions for the analysis. The continuum is assumed as a multi-component phases of water and steam with air. The saturation pressure and hydrostatic pressure of water are defined as user function.

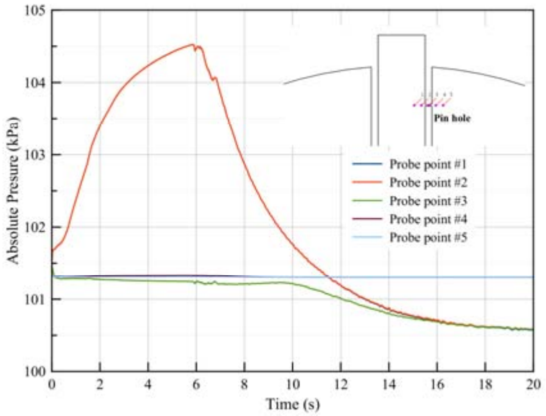

Fig. 2. Absolute pressure history for pinhole center

(1) The saturation pressure;
interpolateTable(@Table("sat_presure"), "Temp_K", LINEAR, "SatP_pa", $Temperature)

(2) The hydrostatic pressure:

$$\rho_{ref} \times g \times (h_{water\_level} - h_0)$$

$$h_0 : bottom\ \ of\ \ fluid$$

The pressure and temperature conditions in the suppression pool are atmospheric pressure, 48.9 °C. Also the initial condition in the suppression pool consists of air, steam and liquid water having the mass fractions specified in Table 1.

A condensation physics model was added to perform condensation calculation using VOF. The steam mass flux into the suppression pool is 0.468 kg/m^2-s.

2.2 Result

The steam inflow in the suppression pool is chugging flow and the transition region in the condensation mode map [6].

Fig. 2 shows that the pressure at the pin hole position of the sparger pipe is increased by a maximum of 103 kPa in about 6.0 seconds due to the increase in the partial pressure of the non-condensable gas in the initial calculation.

The pressure in the blowdown piping and the pressure in the suppression pool reach the equilibrium state at 11.5 seconds, and the pressure in the pipe decreases due to the condensation. Therefore, the gas with the low temperature is reversely introduced into the pipe as shown in Fig 3.

Fig. 4 and Fig. 5 show the pressure change over time of the blowdown pipe and the discharge of the non-condensable gas and steam within about 6.0 seconds with the fluctuation of the water level in the blowdown pipe.

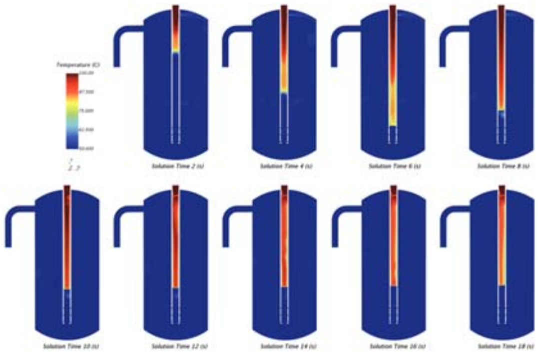

Fig. 3. Temperature distribution with time variation

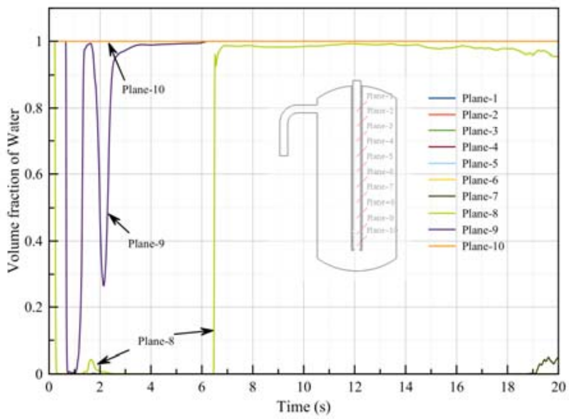

Fig. 4. Water volume fraction time history in blowdown pipe

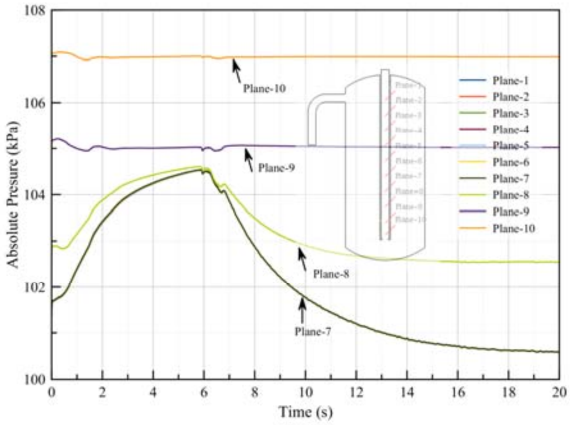

Fig. 5. Absolute pressure time history in blowdown piping

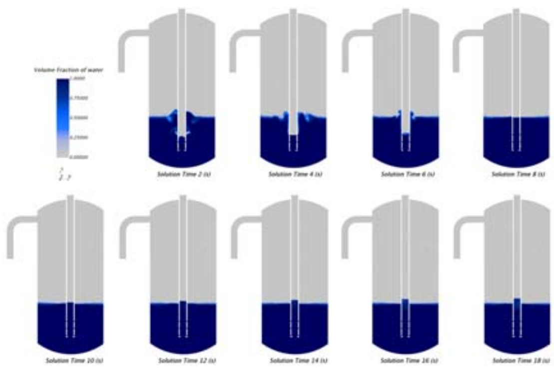

Fig. 6. Mass fraction of water with time variation

The initial water level in the suppression pool is between Plane-7 and Plane-8 in Fig. 4. As the result, the pressure inside the pipe is predicted to be lower than the atmospheric pressure due to the progress of condensation in the blowdown pipe.

The pressure difference between Plane-7 and Plane-8 is 1.94 kPa, and the water level in the pipe is increased by 198 mm at 20 seconds as shown in Fig. 6

3. Conclusions

The Direct Contact Condensation was analyzed on the steam injected into the suppression pool. As a result of the influence of the pin holes in the suppression pool, it is possible to prevent the chugging flow under the low steam flow rate in the blowdown pipe, but the pressure in the pipe becomes lower than the atmospheric pressure, and the condensation occurs only in the blowdown pipe.

In the future, the condensation phenomenon in the suppression pool for an increased steam flow rate and integrity evaluation by the peak pressure will be performed.

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