Numerical Simulation of Pool Film Boiling Heat Transfer during Quenching of Heated Cylindrical Rods

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Introduction: This research investigates technical options to mitigate failure of a nuclear reactor, in which the coolant supply to the nuclear core has been compromised, known as Loss of Coolant Accident (LOCA).

Minimum film boiling temperature (T_{min}) is defined as the minimum point in the boiling curve that sustain a stable vapor film around a heated surface. The effect of liquid subcooling and surface materials T_{min} is studied. The model geometry and boundary conditions are shown in Figure 1.

Rod's Diameter
9.5 mm
Rod's Length
25 cm length

Bath's Diameter
30 cm
Bath's Height
50 cm

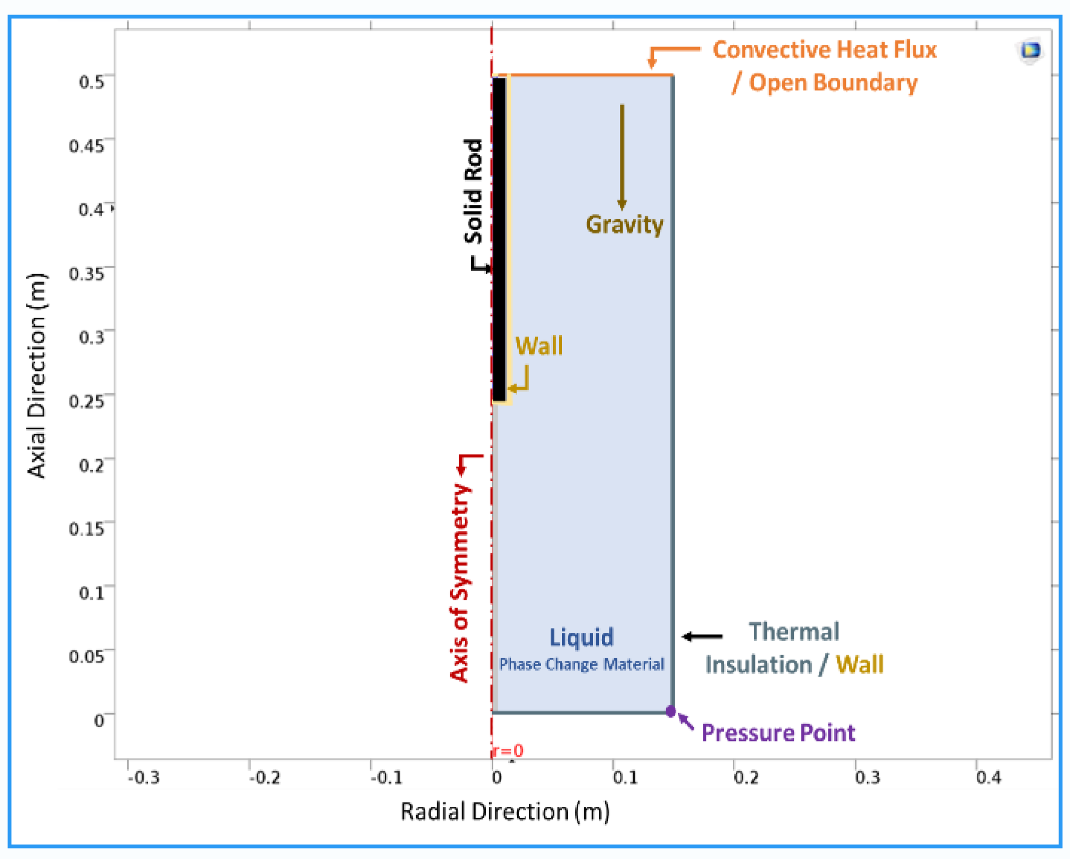

Figure 1. Computational Domain

Computational Methods: The calculated Ra at an initial temperature of 550°C and saturated liquid equals to 2.7×10^{11}. The critical Ra from transition to turbulent in a vertical natural flow is 10^9 [1].

Turbulent flow (k-ω) combined with heat transfer in fluid and phase change models were selected to simulate the model. The continuity, momentum, and energy governing equations have been solved by COMSOL.

Mesh Study: The wall-lifts-off may is checked as seen in Figure 2 due to its effects on the accuracy of the results in turbulent model.

The recommended wall-lifts-off on most of the walls is 11.06 [2]. as shown in Figure 2.

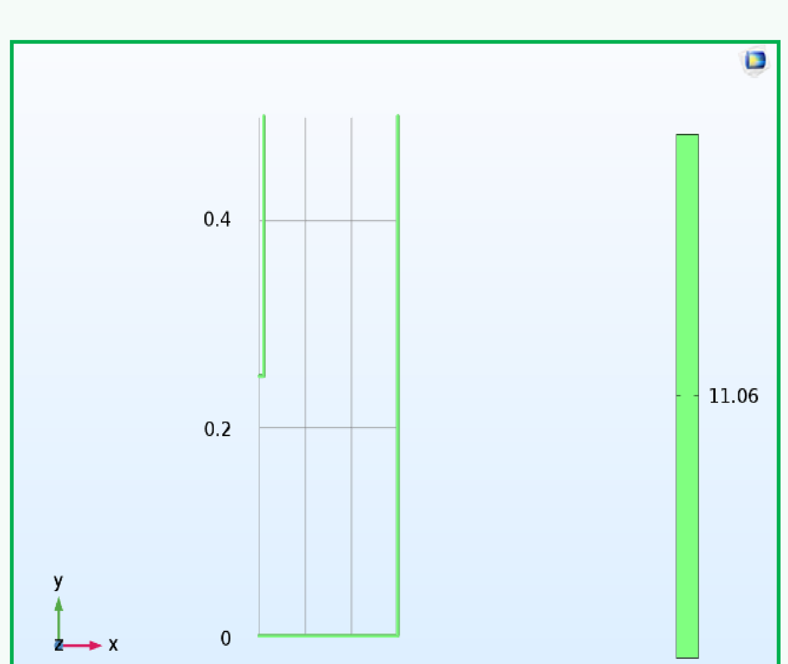

Figure 2. Wall-lift-off

Results: Visualization results show that the vapor film thickness decreases as the liquid subcooling increases as shown in Figures 3 and 4

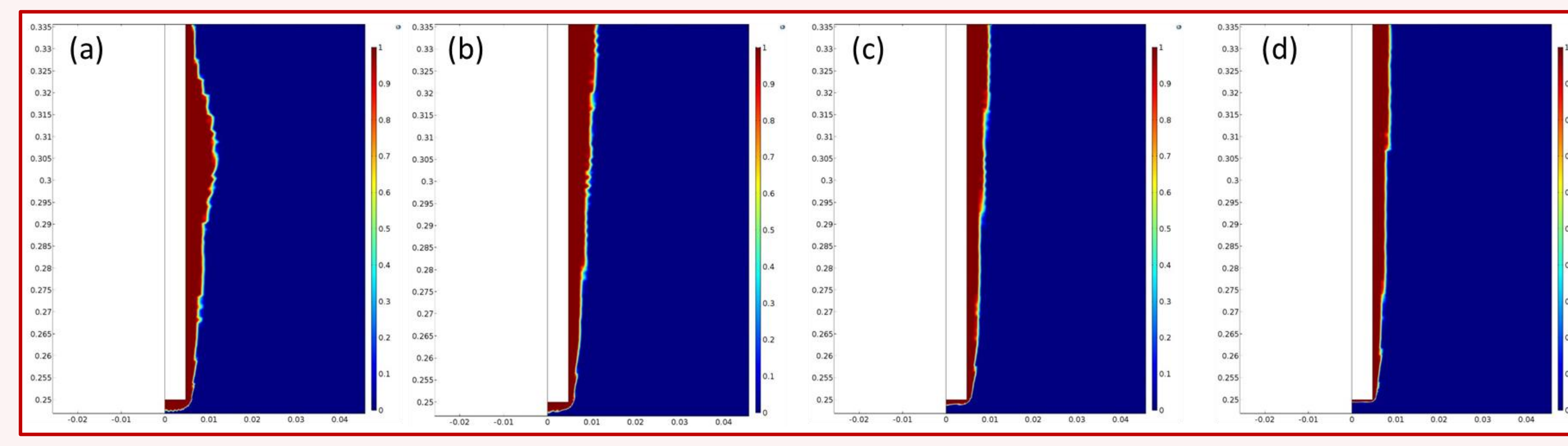

Figure 3. Simulated vapor film plunged in two degrees of liquid subcooling bath at various time; (a) 5 sec, (b) 15 sec, (c) 25 sec, and (d) 35 sec

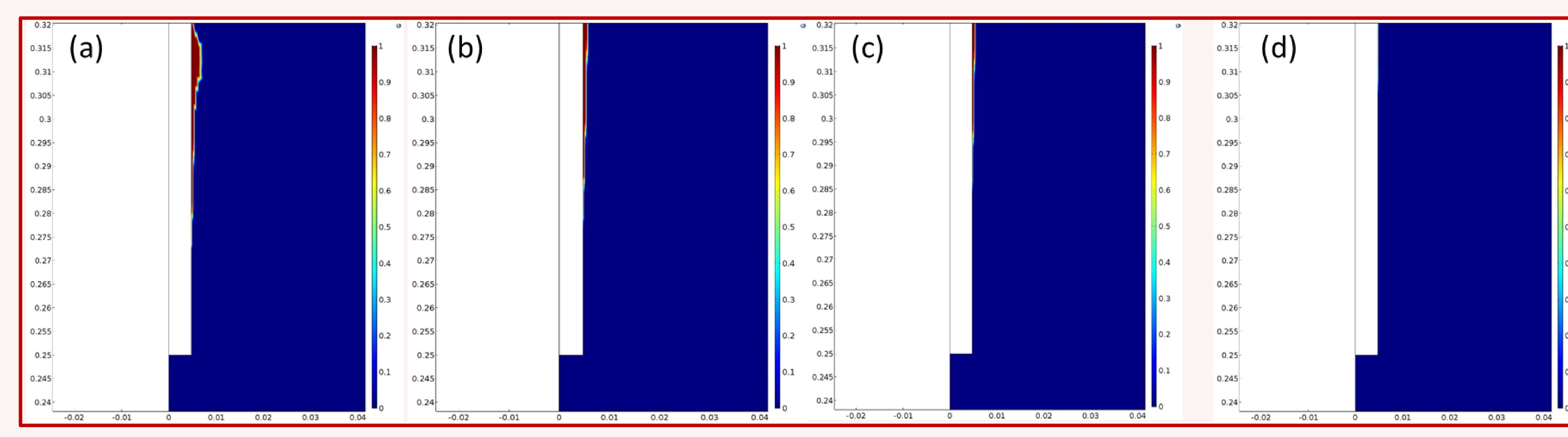

Figure 4. Simulated vapor film plunged in ten degrees of liquid subcooling bath at various time; (a) 5 sec, (b) 15 sec, (c) 25 sec, and (d) 35 sec

Figure 5 represents the simulated boiling curves. Figure 5a indicates that increasing liquid subcooling, increases T_{min}. Figure 5b indicates that as the thermal properties of the surface increases, T_{min} decreases.

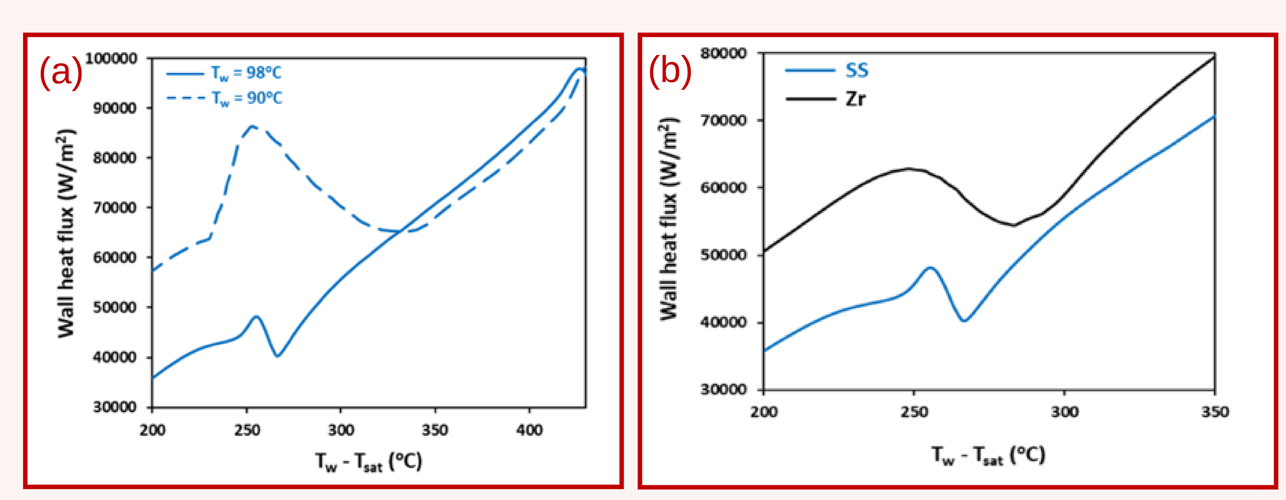

Figure 5. Simulated boiling curves; (a) various subcooling and (b) various surface materials

Conclusions: This research shows the ability of COMSOL to simulate the quenching process under pool boiling conditions.

A comparison of the experimental and simulated T_{min} values are listed in Table 1

Table 1. Experimental and Simulated T_{min} Values

Substrate	Experimental (°C)	Simulated (°C)	Error %
Stainless Steel ΔT_{sub} = 10°C	355	420	18.3
Stainless Steel ΔT_{sub} = 2°C	320	367	14.6
Zirconium ΔT_{sub} = 2°C	389	393	1.0

References:

1. Cheng, K. C., T. Obata, and R. R. Gilpin. "Buoyancy effects on forced convection heat transfer in the transition regime of a horizontal boundary layer heated from below." Journal of heat transfer 110.3 (1988).
2. COMSOL, COMSOL tutorial of wall functions. (2013).