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Numerical Analysis on Temperature Variation of Coolant in Pressurizer Spray Nozzle Considering Vapor Condensation

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1. Introduction

Coolant is discharged into the pressurizer via a spray line pipe and nozzle. However, when the shut-off valve is closed, the coolant flow rate is abruptly reduced and the vapor could be flow upward into the spray nozzle. The inflow of vapor might cause rapid temperature increase and thermal stress problem on the nozzle and weld zones. To estimate the thermal stress applied to the weld zones of pressurizer spray nozzle, internal temperature distribution of the spray nozzle should be identified. Thus, in this paper, numerical analysis has been carried out in order to obtain temperature variation data of coolant near inner nozzle surface.

Fig. 1. Configuration of Spray Line Pipe and Nozzle attached on the Pressurizer

2. The Pressurizer Spray Nozzle Model

The calculation domain is composed of spray nozzle, spray line pipe, spray head and pressurizer head. The spray line pipe is welded to the top of the spray nozzle. And the Spray head is attached on the bottom of the spray nozzle. The spray nozzle consists of nozzle forging, butter, safety end, thermal sleeve, coupling, and so on. The 3D CAD model of the pressurizer spray nozzle is shown in Fig. 2. The analysis domain has solid and fluid zones.

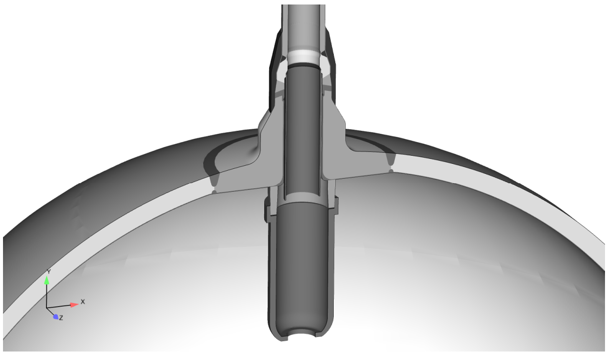


Fig. 2. 3D CAD Model of the Pressurizer Spray Nozzle

3. Numerical Analysis Method

The 3D unsteady CFD analysis has been conducted with VOF model for two-phase flow. To calculate the flow and temperature field, continuity equation, momentum equation and energy equation has been used. To include turbulent effect, SST turbulence model is also adopted. Condensation phenomenon of the vapor flows into the nozzle is treated with a phase change model. About 560,000 grids are used in the entire calculation domain for the CFD analysis(Shown in Fig. 3). Boundary conditions considered in the numerical analysis are shown in Table 1, which are decided based on the operating condition during heat-up. The state of vapor in the pressurizer is similar to the saturation condition. Material properties of solid structures and fluids have been applied as a function of temperature.

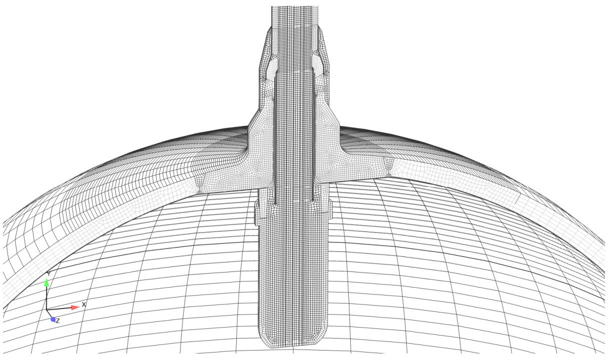


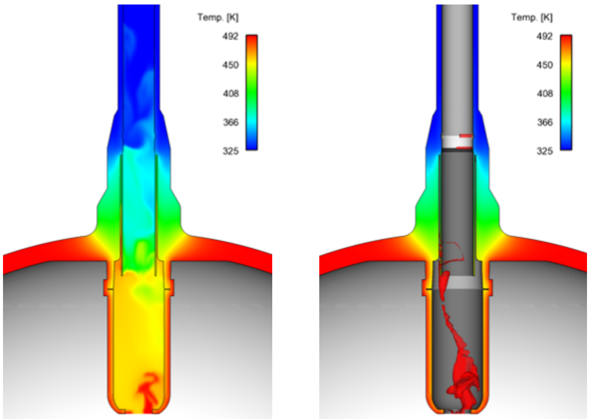
Fig. 3. Grid System

Table 1. Boundary Conditions

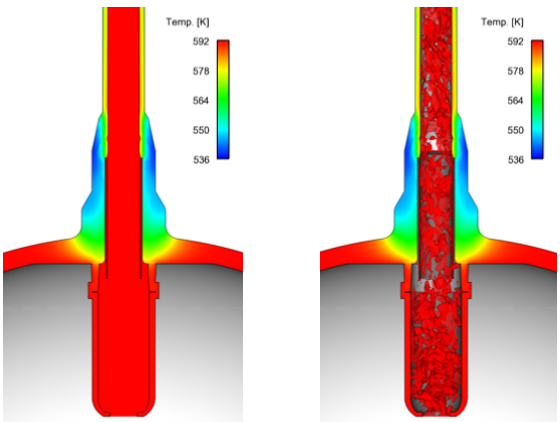
Case #	Pressure	PZR(vapor) Temperature	RCS(water) Temperature
Case 1	325 psia	425 ˚F	125 ˚F
Case 2	1,600 psia	605 ˚F	505 ˚F

4. Results

Temperature distribution in the spray nozzle and behavior of the vapor flows into the nozzle are shown in Fig. 4 and Fig. 5. And graphs of temperature variation with time are shown in Fig. 6 and Fig. 7. In case 1, temperature difference between coolant(RCS) and vapor(PZR) is relatively large(300˚F). Therefore, the vapor is condensed immediately. And it takes temperature of coolant in the spray head a long time to reach the saturation temperature. Meanwhile, in case 2, since coolant temperature in the spray head reaches the saturation temperature rapidly, relatively small amount of the vapor is condensed. Thus, a large amount of vapor flows upward into the nozzle and pipe.



(a) Temperature Contour (b) Vapor Behavior
Fig. 4. Temperature Contour & Vapor Behavior (Case1, t=60s)



(a) Temperature Contour (b) Vapor Behavior
Fig. 5. Temperature Contour & Vapor Behavior (Case2, t=60s)

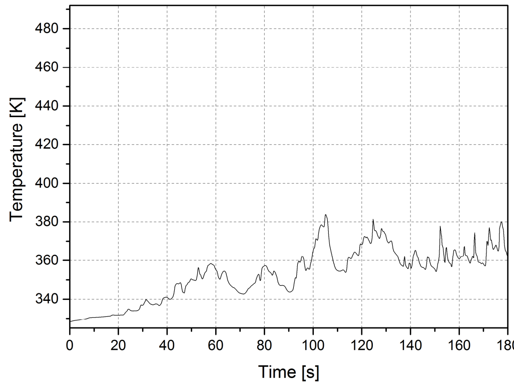


Fig. 6. Temperature Variation of Coolant near the Nozzle to Safety End Weld (Case 1)

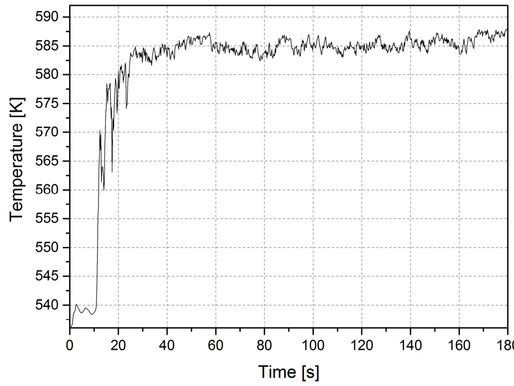


Fig. 7. Temperature Variation of Coolant near the Nozzle to Safety End Weld (Case 2)

5. Conclusions

Numerical analysis has been carried out to obtain coolant temperature variation data for the estimation of thermal stress applied on the spray nozzle and weld zones. The results show below.

In case 1(temperature difference between coolant and vapor is relatively large), it takes temperature of coolant in the spray head a long time to reach the saturation temperature. And the vapor flows into the nozzle is condensed immediately. Therefore, thermal stratification occurs in the spray nozzle and pipe.

In case 2(temperature difference between coolant and vapor is relatively small), since coolant temperature reaches the saturation temperature rapidly, relatively small amount of vapor is condensed. And a large amount of vapor is permeated to the nozzle and pipe. Due to mixing effect of vapor, temperature distribution in the spray nozzle and pipe is relatively uniform.

REFERENCES

[1] J. C. Weimer, G. M. Faeth and D. R. Olson, Penetration of Vapor Jets Submerged in Subcooled Liquids, AlChE Journal, Vol. 19, No. 3, p.552, 1973.