Numerical Study of Thermal Hydraulic behavior of Pressurizer for PLCS Scenario by CUPID Code

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1. Introduction

For a malfunction of a pressurizer level control system, a chemical and volume control system (CVCS) charging flowrate becomes a maximum level and a letdown flowrate a minimum level as well. Consequently, a water level and pressure of pressurizer is abnormally increased, which causes a pilot operated relief valve (POSRV) opened. It becomes important to investigate that a mixture from the POSRV becomes single-phase gas or two-phase mixture.

In this study, the three-dimensional thermal-hydraulic behavior inside the pressurizer is numerically investigated by the CUPID code. The flow fields highly depend on some parameters such as subcooling of the stored water, interfacial drag model and POSRV opening. Thus, these parameters are examined in this study.

2. Numerical Methodology

2.1 Governing equation

The CUPID code [1,2] adopts the two-fluid model for two-phase flows. In the two-fluid model, the mass, energy, and momentum equations for liquid and vapor phases are established separately, and then, they are linked by the interfacial mass, momentum, and energy transfer models. For a mathematical closure, the constitutive relations for the interfacial momentum transfer, the interfacial heat transfer and the wall heat partitioning are necessary.

2.2 Modeling Pressurizer

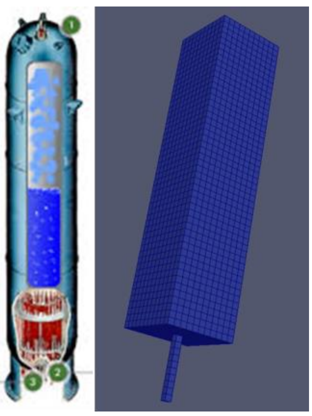


Fig 1 Schemetics and computational mesh

Since the purpose of the study is to investigate is to investigate a global flow behavior of interface and suppressed gas flow due to a relief from the POSRV rather than a local behavior, the pressurizer is simply modeled by using rectangular cells as shown in Fig. 1. The surge line is connected to the bottom. Preheater is assumed to be shut down for this simulation scenario. Moreover, since the local behavior around the preheater is negligible, the preheater is not taken into account.

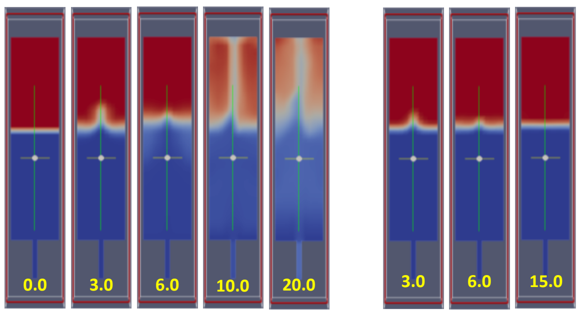
2.3 Boundary conditions of surgeline and POSRV

In order to simulate the charging flow from the surgeline, the lowest cell is assumed to be equivalent to the entire volume of reactor coolant system. Friction and form loss factor are properly model to calculate the charging flow. The POSRV is assumed to open at 2540 psia and close at 2070 psia. In general, the flow from the POSRVs is choking flow, a critical flow model is adopted when the POSRVs are activated. Thus, the choking flow model is applied during the activation of the POSRV.

3. Results and Discussion

3.1 Simulation results

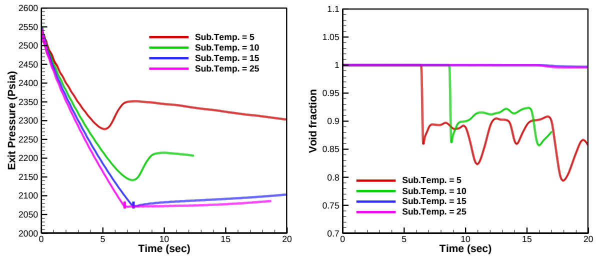
Initially, the water level is 20.6 ft. and the pressure inside the pressurizer is assumed to be 2530 psia which prior to opening the POSRV. Since the system pressure of the big volume at the bottom is assumed to be higher than the initial pressurizer pressure, the POSRV is initially closed. Once the pressure is over 2540 psia, the critical flow model start to work and the suppressed gas at upper region is discharged.



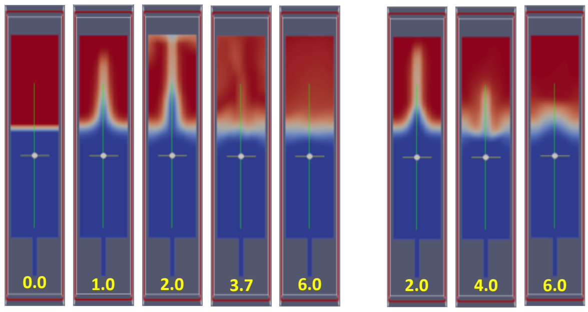
(a) Sub. Temp. = 5K (b) Sub. Temp. = 25K

Fig. 2 Void fraction distribution

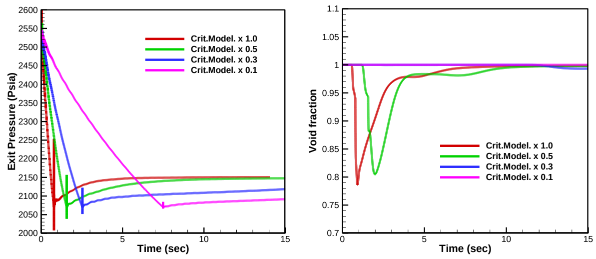
Fig.2 shows the void fraction distribution according to the subcooling temperature of the stored liquid. When the subcooling temperature is less than 10K, the flashing occurs and liquid plume penetrated up to the upper dome of the pressurizer. Thus, the two-phase mixture is discharged through the POSRV. On the other hand, subcooling temperature which is larger than 15K makes the flow stable as shown in Fig 2(b). Fig 3 shows the exit pressure and void fraction at the POSRV. From the Fig 3(b), it is noted that two-phase mixture is discharged through the POSRV.



(a) Exit pressure (b) Void fraction
Fig. 3 Profiles of exit pressure and void fraction at POSRV according to the subcooled temperature.



(a) Opening area × 0.5 (b) Opening area × 0.3
Fig. 4 Void fraction distribution



(a) Exit pressure (b) Void fraction
Fig. 5 Profiles of exit pressure and void fraction at POSRV according to the POSRV opening.

The other parameter that affects the thermal-hydraulic behavior can be which critical model is adopted. Since the boundary condition for the POSRV is treated as exit velocity, it depends on the flow area which is valve opening area. Thus, a sensitivity for opening area is examined. In this study, the subcooling temperature is fixed as 15K which results in the stable flow behavior. Fig. 4 and Fig. 5 show the void fraction distribution and history of presusre and void fraction at the POSRV. As the flow area is smaller, the pressure decreases more gradually due to less discharged flow rate. Moreover, only gas phase is discharged as shown in Fig. 4(b). Larger valve opening area makes the pressure decreases dramatically and the interface unstable. As shown in Fig 4(a), the liquid plume is impinged up to upper wall. Thus the two-phase mixture is observed through POSRV. The less flow area is, the less a fluctuation of the interface is.

4. Conclusions

The three-dimensional thermal-hydraulic behavior inside the pressurizer is numerically investigated by the CUPID code. The flow fields highly depend on some parameters such as subcooling of the stored water, interfacial drag model and POSRV opening. Thus, these parameters are examined in this study.

Less subcooling temperature makes the flow behavior unstable and flashing occur. The two-phase mixture is discharged through the POSRV. Moreover, less flow area delays a discharging flow rate. A sensitivity for the other parameters such critical flow model should be examined for the future work.

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REFERENCES

[1] H.Y. Yoon et al., “Recent Improvements in the CUPID Code for a Multi-Dimensional Two-Phase Flow Analysis of Nuclear Reactor Components, Nuclear Engineering and Technology, 46, pp.655-666 (2014)
[2] S.J. Lee et al., CUPID 1.9 Code Manual Vol.I: Mathematical models and solution methods, KAERI/TR-61022015 (2015).