Reactor Coolant Gas Vent System Performance Analysis Using Commercial Tool

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1. Introduction

The Reactor Coolant Gas Vent System (RCGVS) is required to provide a safety-grade means of remotely venting non-condensible gases from the Reactor Vessel Closure Head (RVCH) and the pressurizer (PZR) steam space during post-accident conditions when large quantities of non-condensible gases are supposed to be collected in these high spots. In addition, the RCGVS is required to provide a safety-grade means of remotely removing steam from the RVCH and the PZR steam space for pressure control in the event that the use of PZR main and auxiliary spray systems is unavailable.

In this study, the performance of the RCGVS has been evaluated with FloMASTER, 1D-CFD modeling tool. The results were compared with the reference hand calculation and RELAP code to see its applicability to the actual system design and analysis.

2. Analysis Methods

2.1 Initial Conditions and Analysis Model

For the RCGVS performance analysis, Loss Of Offsite Power (LOOP) is assumed as an initial condition. Reactor Coolant Pumps (RCPs) are not in operation and there is no charging to the Reactor Coolant System (RCS). The RCS is assumed at normal operation pressure and temperature condition and PZR with 50% water level.

The pressurizer model of FloMASTER was selected as a flash tank. Flash tank is a vessel where the liquid enters and flashes into vapor. The vapor exits near the top of the vessel and the remaining liquid that does not flash into vapor is collected in the bottom of the vessel where it can be drained away [1]. Closed valves were modelled to the front and rear ends of the PZR not to allow any charge and leakages.

2.2 Analysis Methodology

The RCGVS venting path can be selected from either Pressurizer or RVCH as needed. This time, the analysis was performed for the PZR venting flow path. It is assumed that the steam discharge from one nozzle is routed to the ultimate heat sink (IRWST). To simplify the analysis, the valve and the reducer and enlarger of piping were minimized.

Modelings of two units were performed that reflected design changes from the standard APR1400. First one is domestic unit which is added the flow restrictor, orifice. Second one is foreign unit which is chose to remove the RDT path and series valves.

2.3 Modeling Power Plant 1

The configuration of power plant 1 is shown in Figure 1, and the applied modeling is shown in Figure 2.

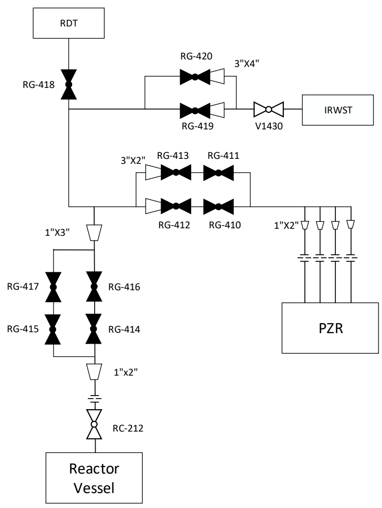

Fig. 1. Configuration of Power Plant 1

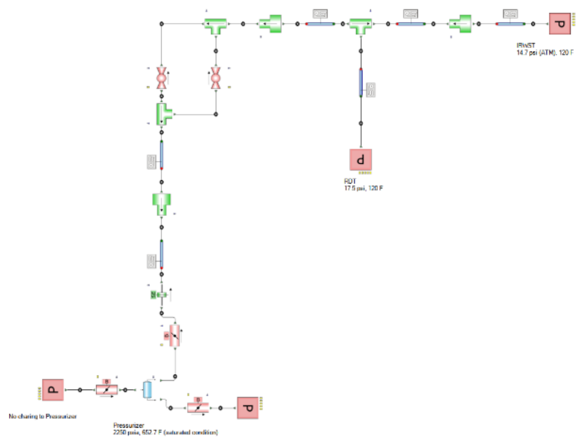

Fig. 2. FloMASTER Modeling of Power Plant 1

2.4 Modeling Power Plant 2

The configuration of power plant 2 is shown in Figure 3, and the applied modeling is shown in Figure 4.

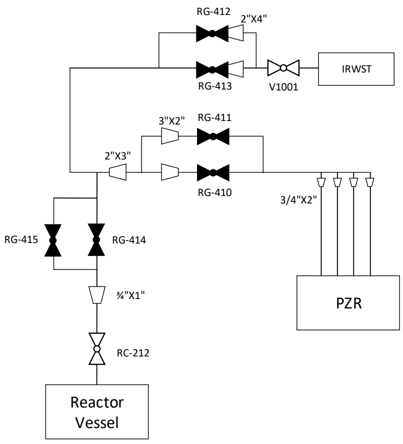

Fig. 3. Configuration of Power Plant 2

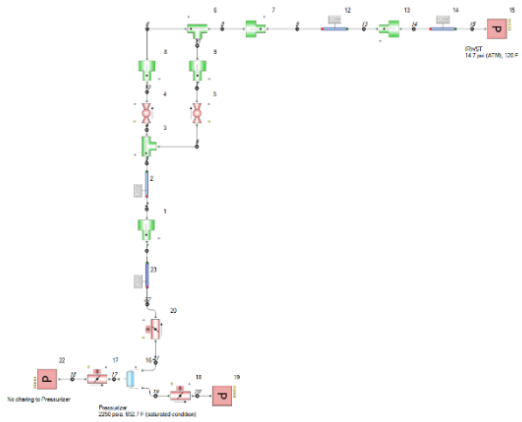

Fig. 4. FloMASTER Modeling of Power Plant 2

3. Analysis Results

3.1 Analysis Results of Power Plant 1

Figures 5 through 7 are the analysis results of the major parameters of power plant 1. In Figure 5 and Table I, the steam venting mass flow rate is higher than the hand calculation which has been obtained by using the Fanno Flow Model (FFM) and isometric drawing. It is found multiple chokings occur at the enlargers of the piping while the FFM assumes that choking occurs at the end of piping and does not take into account the condensation of the fluid flow process [2].

In Table I, FloMASTER is compared to the hand calculation and RELAP computer code. Although RELAP is calculated to have more sufficient venting flow rate than the hand calculation, the result is similar within 1.4% between FloMASTER and RELAP.

Table I: Comparison of Venting Mass Flow Rate

	Hand Calculation	FloMASTER	RELAP
Flow rate (kg/s)	1.74	2.15	2.18*

* The analysis is performed at 2,500 psi in RELAP. However, it is found that the margin between hand calculation and RELAP is reduced as decreasing the venting pressure.

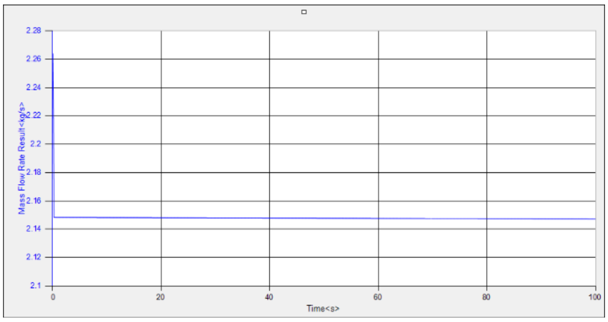

Fig. 5. Power Plant 1-PZR Venting Mass Flow Rate

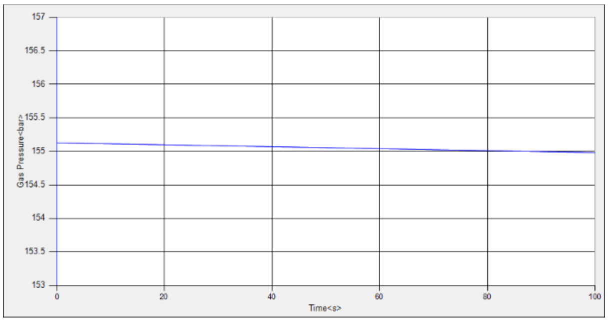

Fig. 6. Power Plant 1-PZR Pressure

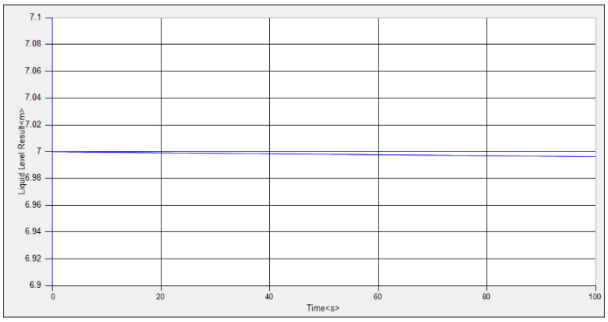

Fig. 7. Power Plant 1-PZR Water Level

According to Figures 5 through 7, even though the venting flow rate is more excessive than the hand calculation, the PZR pressure and water level drop are insignificant. It is because the duration for the analysis is 100 seconds, and the initial water of inventory of PZR is relatively massive.

3.2 Analysis Results of Power Plant 2

Figures 8 through 10 are the analysis results of the major parameters of power plant 2. In Figure 8 and Table II, the steam venting mass flow rate is higher than the hand calculation. The RCGVS piping was already designed before applied the design changes as followed a previous requirement that was higher than the present.

In Table II, FloMASTER is compared to hand calculation and RELAP computer code. Although RELAP is calculated to have more sufficient venting flow rate, the result is similar within 6% between FloMASTER and RELAP.

Table II: Comparison of Venting Mass Flow Rate

	Hand Calculation	FloMASTER	RELAP
Flow rate (kg/s)	3.66	6.44	6.84**

** The analysis is performed at 2,500 psi in RELAP. However, it is found that the margin between hand calculation and RELAP is reduced as decreasing the venting pressure.

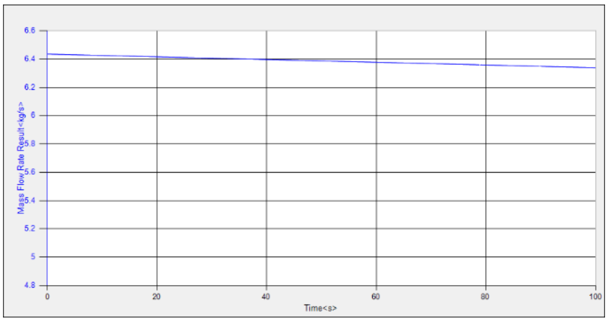

Fig.8. Power Plant 2-PZR Venting Mass Flow Rate

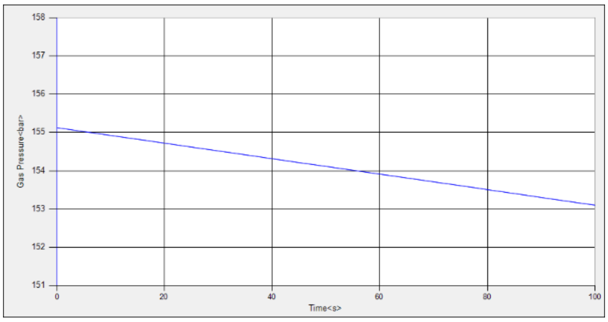

Fig.9. Power Plant 2-PZR Pressure

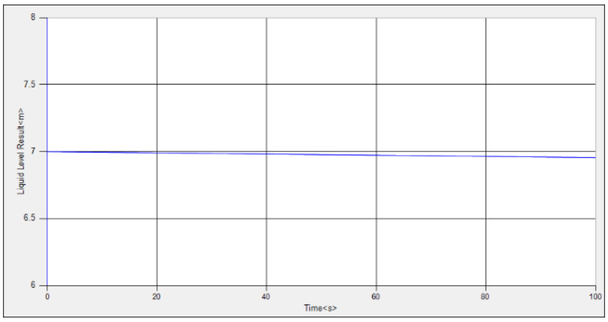

Fig.10. Power Plant 2-PZR Water Level

Figure 5 and 8 show that the steam venting flow rate of power plant 1 is considerably less compared to that of power plant 2 because the orifice installed at the end of the PZR served as a flow restrictor. According to Figure 6 and 7, the PZR pressure and water level drop are much less than that of power plant 2, since the venting flow rate is approximately 33% of power plant 2. The higher depressurization rate is achieved by higher vent flow.

4. Conclusion

The performance of the RCGVS has been evaluated with an 1D-CFD modeling tool, FloMASTER. It is considered the actual venting flow rates are between the hand calculation and the RELAP code. It is confirmed that the venting flow rates of the FloMASTER were similar to RELAP. It is expected that the FloMASTER can be utilized as a verification tool for simple transient analysis or system design.

REFERENCES

[1] Simcenter Flomaster Components Reference Manual-Software Version 2019.3, Siemens, Nov. 2019.

[2] H.A. Kim, A Bounding Evaluation of Minimum Steam Venting Capacity in Reactor Coolant Gas Vent System Designer for APR1400, Korean Nuclear Society Autumn Meeting, 2019.

[3] Crane Company, Technical Paper No. 410, Flow of Fluids through Valves, Fittings, and Pipe, British Unit, 2009.