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An Evaluation of Discharge Flow of Safety Depressurization System Valve using 1D-Computational Fluid Dynamics

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1. Introduction

The Safety Depressurization System (SDS) shall provide a safety-grade means of rapidly depressurizing the RCS during the beyond design basis event of a Total Loss of Feedwater (TLOFW). It is used in conjunction with the Safety Injection System to provide once-through-core-cooling.

The SDS shall prevent exposure of the fuel to containment atmosphere when 1) only one of the two HPSI pumps is available together with opened PSV after TLOFW accident, 2) two HPSI pumps are available after 30 minutes from PSV opened [1].

If the resistance coefficient of the SDS piping decreases, the discharge rate from the SDS may cause exposure of the fuel to containment atmosphere. It is essential to evaluate the discharge rate from the SDS when the flow path, valves, and instruments are changed.

The purpose of this paper is to simulate the discharge rate from the SDS using FloMASTER [2], the commercial 1D-Computational Fluid Dynamics (CFD) solution and to evaluate its validity by comparing with the results from other evaluation methods when the SDS isolation valves are replaced with other manufacturer's model having different coefficient values (Cv).

2. Methods and Results

FloMASTER is a general purpose 1D-CFD solution for modeling and analysis of fluid mechanics in complex piping systems of any scale.

The transient analysis is performed using FloMASTER computer code. It is assumed that a discharge flow at the SDS inlet of pressurizer occurs during 100% power operation and reactor coolant is discharged into the containment atmosphere through the SDS piping.

2.1 Geometry Configuration

The SDS piping layout shall not include any undrainable loops. Horizontal gradient in the SDS piping shall have a minimum slope of 1/8" per 12" such that any fluid in the horizontal piping will drain towards the pressurizer and/or the Reactor Drain Tank (RDT) via SDS drain line. Piping shall be pitched downwards the pressurizer from the globe valve and the piping downstream of the globe valve shall be pitched downwards the rupture disk.

The SDS isolation valves (431-V-101/102) should be located as close to the pressurizer as practical which will minimize the SDS pipe break probability and the load on the SDS line supports.

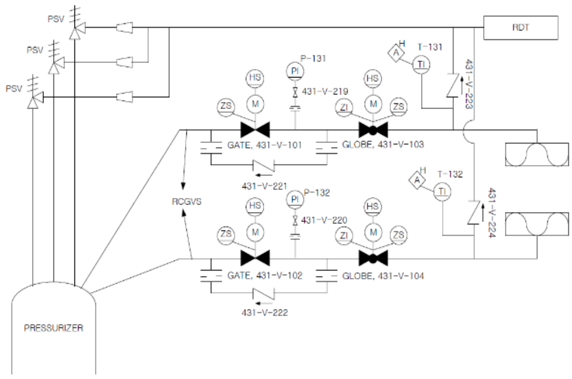

Fig. 1. Piping and Instruments Diagram for SDS

2.2 Discharge of Compressible Steam

In the event of the SDS discharge from pressurizer to atmosphere, the steam shall be considered compressible gas. The steam is compressible in which a specific volume of the fluid increases as the pressure decreases. The pipe resistance of the compressible gas should be considered for the change in density due to compressibility.

According to the American Gas Association (AGA), the discharge flow of the compressible gas is expressed by Equations (1) and (2).

$$\frac{1}{\sqrt{f}} = 2\log\left(\frac{3.7d}{\varepsilon}\right) \qquad (1)\ \text{Ref. [3]}$$

$$\Delta P = 2.799 \times 10^{-7}\,\frac{KW^2}{\rho d^4} \qquad (2)\ \text{Ref. [4]}$$

2.3 Analysis Model and Initial Conditions

Analysis model for the SDS discharge flow is as shown in Figures 2 and 3. Two analysis models, which show the SDS piping including before and after valve replacement, were simulated under two-phase and compressible transient conditions.

Loss-discrete modules, such as opened valves when steam is discharged through the SDS piping, are used to describe flow resistances of the valves. In these modules, the flow coefficient of the valves (Cv) was converted to the pressure loss resistance (K) using Equation (3) to construct the SDS piping with FloMASTER modeling.

$$C_V = 29.84 \times \frac{d^2}{\sqrt{K}} \quad (3)$$

The two-phase and compressible transient models were simulated for 120 seconds with the time-step of 0.1 seconds. In two-phase transients, flash tank module, such as pressurizer when the SDS discharge occurs, is components that continuously separates compressed water into condensate water and steam from the boiler or steam-jet system. In compressible transient, accumulator module is components which simulate pressurizer when the SDS discharge occurs.

The SDS discharge flow is simulated by suddenly opening virtual valves (Cv = 0) within stroke time of the SDS isolation valves (431-V-101/102). The discharge of steam from the SDS piping to a containment atmosphere is simulated by giving abrupt flow area change.

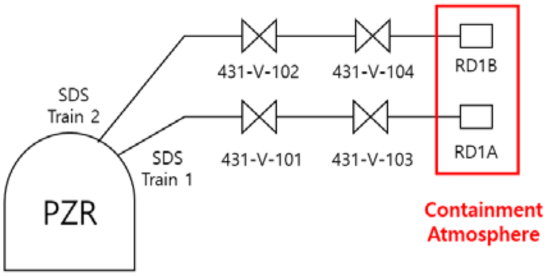

Fig. 2. Schematic configuration for OPR1000 SDS piping

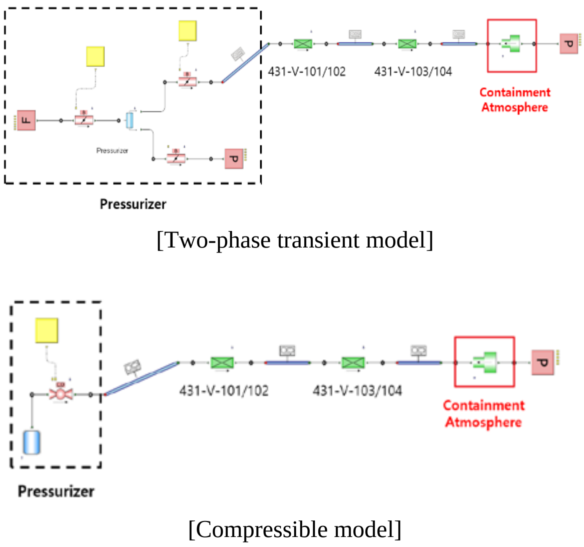

Fig. 3. FloMASTER network diagram for system modeling

The piping length and elevation for the SDS discharge flow evaluation are listed in Table I and the initial conditions for the simulations are listed in Table II.

Table I: Piping Length and Elevation for the SDS Discharge

	Piping Length	Elevation
Train 1		
Pressurizer to 431-V-101	9.249 m	+1.67 m
431-V-101 to 431-V-103	0.743 m	-0.024 m
431-V-103 To RD1A	1.829 m	-0.107 m
Train 2		
Pressurizer to 431-V-102	9.101 m	+1.654 m
431-V-102 to 431-V-104	0.735 m	+0.035 m
431-V-104 To RD1B	1.613 m	-0.102 m

Table II: Initial Conditions for the Simulation [Before (Case A) and After (Case B) Valve Replacement]

	Case A	Case B
Fluid		
Fluid Model	Separated Mixture Model	
Pressure	2,500 psia (17.2 MPa)	
Temperature	668.2°F (353.4°C)	
Piping and valves		
Pipe Heat Transfer	Adiabatic	
Absolute Roughness	0.00015 in (3.81 μm)	
431-V-101/102 Valve Cv	580 (Manufacturer A)	1080 (Manufacturer B)
431-V-103/104 Valve Cv	157 (Manufacturer A)	
Min./Max. Stroke Time	20s / 27s	

2.4 Analysis Results and Evaluation

The results of the transient analysis for the 16 cases used in Tables I and II are as shown in Figure 4. The results of the simulation show that some hunting while the SDS isolation valve is being opened and also after 100% opened. The maximum discharge flow is also reached just before fully valve opening.

Maximum discharge flow rates of FloMASTER computer codes and hand calculations are compared in Tables III. The maximum discharge flow using the FloMASTER was extracted from the data which was applied with 95% confidence level (5% uncertainty) to minimize the error due to hunting.

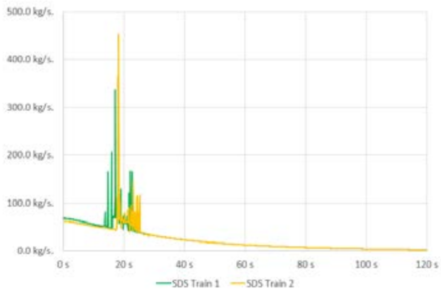

Fig. 4. Results of transient simulation

Table III: Comparison of Maximum Discharge Flow

		Case A	Case B	Change Ratio[1]
FloMASTER: two-phase transient				
Train 1	Valve Stroke Time = 20s	63.164 kg/s (72.7%)	63.123 kg/s (71.2%)	-0.06%
Train 1	Valve Stroke Time = 27s	64.589 kg/s (74.3%)	65.742 kg/s (74.1%)	+1.79%
Train 2	Valve Stroke Time = 20s	62.878 kg/s (72.1%)	65.234 kg/s (73.3%)	+3.75%
Train 2	Valve Stroke Time = 27s	67.365 kg/s (77.2%)	67.412 kg/s (75.8%)	+0.07%
FloMASTER: compressible transient				
Train 1	Valve Stroke Time = 20s	74.365 kg/s (85.5%)	77.204 kg/s (87.1%)	+3.82%
Train 1	Valve Stroke Time = 27s	74.365 kg/s (85.5%)	77.204 kg/s (87.1%)	+3.82%
Train 2	Valve Stroke Time = 20s	72.622 kg/s (83.3%)	77.780 kg/s (87.4%)	+7.10%
Train 2	Valve Stroke Time = 27s	72.622 kg/s (83.3%)	77.780 kg/s (87.4%)	+7.10%
Hand Calculation				
Train 1		86.932 kg/s (100%)	88.662 kg/s (100%)	+1.99%
Train 2		87.213 kg/s (100%)	88.960 kg/s (100%)	+2.00%

[1] Change ratio (%) = $\frac{(After-Before)}{Before} \times 100$

The results of the FloMASTER simulation show that discharge flow from 72.0% to 87.4% are evaluated comparing to the hand calculation. The change rates of discharge flow between before and after valve replacement are -0.06% to +7.10%. The change ratio of compressible transient shows the greater change ratio than that of hand calculation.

In the results, the discharge flow using FloMASTER is approximately higher in compressible transient than that of two-phase transient. The simulation results using compressible transient show a higher change ratio than that of two-phase transient when the flow resistance is changed after valve replacement.

3. Conclusions

Simulation results show that the change in the discharge flow rate is within a maximum of 10% after the SDS isolation valves is replaced. Therefore, the decrement of resistance coefficient from valve replacement shows that the increment of the SDS discharge flow is within the safety margin.

This paper evaluated and compared the SDS discharge flow between FloMASTER and hand calculation. It was identified that the discharge flow using FloMASTER has less discharge flow than hand calculation.

In conclusion, the results between FloMASTER and hand calculation are about 20-30% different, so it is estimated that FloMASTER can be utilized in preliminary discharge evaluation.

NOMENCLATURE

f = darcy friction factor
K = resistance coefficient
ρ = density of the steam (lb/ft^3)
d = inner diameter of the SDS piping (inch)
ε = absolute roughness of the piping (inch)
ΔP = differential pressure between inlet and outlet piping (psid)
W = mass flow rate of the discharge steam (lb/hr)
C_v = flow coefficient for valves

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