Comparison between the 2D axial symmetric model and the 3D model of a safety valve

S. K. Kang, D. H. Lee, S. K. Park
Nuclear Power Laboratory, Korea Electric Power Research Institute, 103-16 Munji-dong, Yusung-Ku, Daejeon, skkang@kepri.re.kr

1. Introduction

Safety valves are used as part of the overpressure protection system in various power, process and industrial applications. To investigate the safety valve, analytical model is needed. 2D axial symmetric model is used frequently due to its simplicity. However, the exact solution is obtained by using 3D model, which requires a great deal of analysis time. In this study, comparison between 2D axial symmetric model and 3D model is carried out from the viewpoint of flow capacity. Furthermore, K_D(discharge coefficient) is calculated and compared for two guide ring positions.

2. Methods and Results

Related with studies of flow simulations, several studies have been carried out. Kang studied the effect of ring position on the fluid flow in safety valve by using 2D axial symmetric model[1]. Also, Kang *et. al.* simulated the dynamic flow in safety valve using 2D model with chimera grid and 6DOF model which are provided in CFD-FASTRAN[2]. A. J. Reich *et. al.* simulated the opening of the Target Rock Vacuum Relief valve using 2D axial symmetric model with CFD-ACE+ and MDICE[3]. These studies were carried out from the viewpoint of 2D model. However, there is no study which investigates the difference between 2D axial symmetric model and 3D model, which is the purpose of this study.

The comparison is carried out from the aspect of flow capacity and K_D. The flow capacity is calculated from the result of simulations. K_D is calculated by using the flow capacity and theoretical flow rate. Theoretical flow rate for safety valve which manages steam, is calculated according to Napier equation[4] as:

$$W_T = 51.5 \cdot A \cdot P \quad (1)$$

where
W_T = theoretical flow rate, lbm/hr
A = discharge area with the valve fully open, in^2
$P = 1.1 \times$ Setting pressure + Atmosphere pressure, psi
During simulations, upstream pressure of safety valve is assumed as 'P'.

The 2D axial symmetric model and 3D model are composed of inlet pipe, safety valve and outlet pipe which are meshed with structural grid. The inlet condition that is 14.5MPa and its saturated temperature(612.7K) is enforced at the inlet pipe. The outlet condition of atmospheric pressure and temperature(0.1MPa, 293K) is given to the outlet pipe. The initial pressure and temperature are 4Mpa, 400K. Initial velocity is given as 100m/sec. The schemes such as VanLeer's FVS and Van-Leer(L) for flux splitting and flux limiters are used. The molecular weight and the specific ratio are 18 and 1.25, respectively.

The comparison is carried out for two conditions that have different position of guide ring. One condition locates guide ring 2mm below the seat surface(case 1) and the other locates guide ring 11mm above the seat surface(case 2), while nozzle ring is located 4.5mm below seat surface.

2.1 2D axial symmetric model

Figure 1 shows the pressure of case 2. The pressure decreases drastically through the safety valve. The density, velocity and coordinates are measured through the sectional line that is located at the nozzle. Using these data, the flow capacities are calculated as 143.3kg/sec and 146.7kg/sec for case 1 and case 2, respectively. The guide ring below seat surface disturbs the flow, therefore the flow capacity of case 1 is lower than that of case 2. The upstream pressures of safety valve are measured as 1396.7psi and 1370.0psi. With these values, theoretical flow rates are calculated as 148.9kg/sec and 155.8kg/sec. Therefore, K_D is calculated as 0.90 and 0.94 for case 1 and case 2.

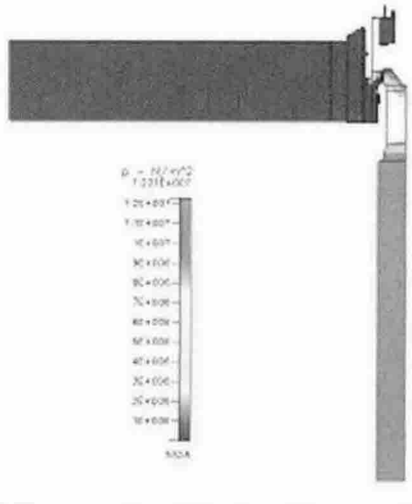

Figure 1. Pressure of case2 for 2D axial symmetric model

2.2 3D model

The pressure of case 2 is shown in Figure 2. Because 3D model solves the shape of safety valve, the closed side of the safety valve which is the right of the safety valve in Figure 2, is displayed. The density, velocity and coordinates are measured at same location above the 2D axial symmetric model. The flow capacities are calculated as 141.0kg/sec and 145.0kg/sec for case 1 and case 2, respectively. The effect of guide ring is shown between these flow capacities. The upstream pressures for case 1 and case 2 are measured as 1533.5psi and 1508.0psi. Therefore, case 1 and 2 have 174.4kg/sec and 171.5kg/sec as theoretical flow rates, which results in 0.81 and 0.85 as K_D. Compared with 2D model, the flow capacity, theoretical flow rate and K_D are lower.

Due to the characteristic of 2D axial symmetric model, which has larger outlet area than 3D, its resistance to flow is low, therefore flow rate becomes large and the upstream pressure becomes small. This produces small theoretical flow rate and large K_D in 2D axial symmetric model.

3. Conclusion

2D axial symmetric model predicts the flow rate larger and upstream pressure smaller than 3D model. Therefore, the theoretic flow rate calculated is smaller than that of 3D model, which results in larger K_D of 2D axial symmetric model.

REFERENCES

[1] S. K. Kang, A study on fluid flow of safety valve, Proceedings of the Korea Nuclear Society Autumn Meeting Younpyoug, Korea, October, 2003. p.493.

[2] S. K. Kang, D. H. Lee, S. K. Park and S. L. Hong, A Computational Method to Predict Fluid-Structure Interaction of Pressure Relief Valves, Proceedings of the Korea Nuclear Society Autumn Meeting Gyeongju, Korea, May 2004. p.117.

[3] A. J. Reich, V. Parthasarathy and A. DiMeo, Coupled Fluid-Structure Interaction Simulation of the Opening of the Target Rock Vacuum Relief Valve, ASME Pressure Vessels and Piping Conference, 2001.

[4] KEPIC MNC 7000.

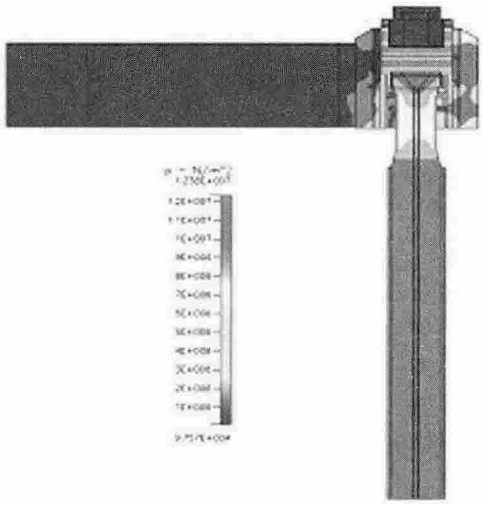

Figure2.Pressure of case 2 for 3D model