NUMERICAL STUDY ON THE INHIBITION OF CAVITATION IN PIPING SYSTEMS

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Abrupt closing valve in piping systems is sometimes resulted in cavitation due to the occurrence of high pressure difference. The bubbles generating by cavitation influence operating pressure and then those generate shock wave and vibration. These phenomena can consequentially cause to corrosion and erosion. So, the cavitation is the important factor to consider reliability of piping systems and mechanical lifetime. This paper investigated the various inhibition methods of cavitation in piping systems in which butterfly valves are installed. To prevent cavitation occurrence, it is desirable to analyze its characteristics between the upstream and downstream of process valve. Results show that the fluid velocity is fast when a working fluid passed through butterfly valve. The pressure of these areas was not only under saturation vapor pressure of water, but also cavitation was continuously occurred. We confirmed that the effect of existence of inserted orifice and influence to break condition under saturation vapor pressure of water. Results were graphically depicted by pressure distribution, velocity distribution, and vapor volume fraction.

Keywords: Cavitation; butterfly valve; saturation vapor pressure.

1. Introduction

Control valve are used in various industrial plants, such as electricity power station, chemical plants to regulate the process pressure and flow rate of the fluid systems. Many of the valves are operated at extreme levels of fluid pressure. Hence, development of control valve technology is significantly responsible for smooth and high quality control operations. Butterfly valve is popularly used in service in the industrial and piping systems as a flow control valve and it has also bigger flow coefficient than globe valve of the same size. But one of the serious problems such as cavitation phenomena and flashing could be occurred because butterfly valve has essentially high pressure recovery coefficient.

Nomenclature

U	vector of velocity U	μ	molecular (dynamic) viscosity
g	gravity acceleration	τ	shear stress tensor
ρ	density	P	Pressure
R_B	bubble radius		pressure in the bubble assumed
		p_v	to be the vapor pressure at the liquid temperature
P_t	pressure in the liquid surrounding the bubble	ρ_f	liquid density
σ	surface tension coefficient between the liquid and vapor		

For hydrodynamic cavitation, faster pressure recovery rates increase the life of the bubbles¹. Fluid velocity passed through pipe line was increased in the vicinity of butterfly valve due to small valve opening. According to this velocity increment, static pressure drops below saturation vapor pressure. Bubbles are formed at this low pressure domain. When liquid pressure increases, bubbles are rapidly imploded, and then an ambient liquid molecule filled in for the space of imploded vapor and high pressure was locally occurred in a brief². When such high pressure was occurred in the vicinity of the pipe wall, there comes to tensile strength of piping material. Continuous implosion on a small surface causes fatigue of piping material, thus cavitation plays an important role in the design and operation of fluid machinery and devices. Based on evaluation and the analysis of the unsteady characteristics for cavitating flows, Huang et al.³ proposed a modified density based on cavitation model, which concerns multiphase and time scale information for the cavitation flows. Zhang et al.⁴ studied to assess the generality and precision of performance prediction of the full cavitation model by modeling the NASA hydrofoil and NASA ogive in liquid nitrogen with the software package Fluent ver. 6.3. Srinivasan et al.⁵ proposed cavitation-induced-momentum-defect (CIMD) correction methodology account for cavitation inception and collapse events as relevant momentum-source terms in the liquid phase momentum equations. Ying et al.⁶ studied unsteady turbulent cavitation flows in venturi-type section around a NACA0012 hydrofoil.

The aim of present study is to find the inhibition methods of cavitation in piping systems. The commercial CFD software package ANSYS-CFX ver.13 adopts this cavitation model under the strategy of homogeneous model, sufficient to solve for the sheared field using bulk transport equations rather than solving individual basic transport equations and has the capacity of accounting for multiphase flows.

2. Governing Equations

The instantaneous conservation equations of continuity and momentum are as follows:

continuity equation:

$$\frac{\partial(\rho \bar{U})}{\partial t} + \nabla \cdot (\rho \bar{U}) = 0, \quad (1)$$

momentum equation:

$$\frac{\partial(\rho \bar{U})}{\partial t} + \nabla \cdot (\rho \bar{U} \cdot \bar{U}) = -\nabla p + \nabla \cdot \tau. \quad (2)$$

The k - ω based Shear Stress Transport (SST) model which accounts for the transport of the turbulent shear stress is adopted for turbulence analysis. The k - ω based SST model gives highly accurate predictions of the onset and the amount of flow separation under adverse pressure gradients⁷.

The Rayleigh-Plesset model is adopted for multiphase framework as an interphase mass transfer model. The Rayleigh-Plesset equation provides the basis for the rate equation controlling vapor generation and condensation. Also, the growth of a gas bubble in a liquid is given by⁷:

$$R_B \frac{d^2 R_B}{dt^2} + \frac{3}{2} \left(\frac{dR_B}{dt} \right)^2 + \frac{2\sigma}{\rho_f R_B} = \frac{p_v - p_\ell}{\rho_f}. \quad (3)$$

3. Numerical Analysis

The model of elbow pipe line with butterfly valve applied in this study is shown in Figure 1. Figure 2 shows grid systems of the pipe line. Since the shape of the disk plate was complicated, we applied tetra mesh which is suitable for complex geometries without reference to shape. While tetra meshing is not efficient for capturing shear or boundary layers, prism mesh efficiently captures these effects near the surface. Therefore, we applied prism mesh for precision analysis at the boundary layer which applied wall scale effect. The grid system generally was dominated with tetrahedral. Total nodes were about 1,000,000 and total elements were about 4,500,000.

Boundary conditions for numerical analysis were shown in Table 1. With changing the inlet pressure 120~221.3 kPa, we set the inlet pressure to confirm the onset of cavitation phenomena and the flow rate is fixed at the domain outlet. The working fluid was a water of 49°C. The entire wall was used no-slip boundary conditions. The inhibition methods of cavitation such as installing orifice and air vent pipe at the downstream of butterfly valve were applied to piping systems. We compared how cavitation can be reduced by setting the design parameter of orifice hole diameter and by installing air vent pipe.

Fig. 1. Schematic of the piping systems.

Fig. 2. Grid systems of analysis model.

Table 1 Boundary conditions applied to numerical study.

Case	1	2	3
Inlet pressure	120 kPa	171.3 kPa	221.3 kPa
Clearance		10 mm	
Inlet flow rate		5322.67 kg/s	
Reference pressure		1 atm	
Control valve open		33.3 degree	
Working fluid temperature		322.15K	

4. Results and Discussion

Figure 3 shows the total pressure distribution of piping systems with various values of inlet pressure. The Pressure loss by butterfly valve 106 kPa ~ 157.8 kPa and total pressure for the case of inlet pressure 171.3 kPa was dropped below saturation vapor pressure 11.7986 kPa.

Figure 4 depicted the velocity distribution of piping systems. The water velocity was increased in the vicinity of butterfly valve due to narrow clearance between the disk tip and pipe wall. Figure 5 showed the overall vapor volume fraction. It is seen that the vapor distribution was remarkable at low range of inlet pressure. In light of these results, the water velocity was increased through narrow area, which it caused kinetic energy increment and so finally balanced by pressure drop.

Total pressure of the outlet domain was measured at approximately 10 kPa, which was lower than vapor saturation pressure 11.7986 kPa in the 49□.

Figure 6 shows vapor volume fraction when installed orifice at the downstream of butterfly valve. It can be deduced that orifice makes turbulent flow stable by friction loss

of cavities but corresponding pressure drop by orifice, water velocity was increased when passed through orifice. Hence, installing orifice at the downstream of butterfly valve had more effect on the intensity of cavitation occurrence.

Figure 7 shows vapor volume fraction when installed air vent pipe at the downstream of butterfly valve. Installing air vent in the vicinity of butterfly valve is one of the efficient methods for cavitation inhibition. Since air from the vent pipe inflow in the throttle area broke a vacuum of ambient static pressure, the possibility of cavitation occurrence could be decreased.

Fig. 3. Pressure distribution at the center of cross section along the streamwise direction.

Fig. 4. Velocity distribution at the center of cross section along the streamwise direction.

Fig. 5. Vapor volume fraction distribution at the center of cross section along the streamwise direction.

Fig. 6. Distribution of vapor volume fraction at the center of cross section with installing orifice along the streamwise direction.

Fig. 7. Distribution of vapor volume fraction at the center of cross section with vent open and installing orifice along the streamwise direction.

5. Conclusions

In this study, numerical analysis is performed to investigate the inhibition of cavitation occurrence in the piping systems. The following conclusions are obtained.

- 1) As the lower range of inlet pressure, static pressure at the downstream of butterfly valve was dropped below saturation vapor pressure and thus possibility of cavitation occurrence was increased in the piping systems.
- 2) Water velocity started to increase in the vicinity of disk tip because of narrow area so that caused kinetic energy increment. Ultimately, static pressure made the ambient pressure in equilibrium as much as pressure loss in the throttle area, dropped below saturation vapor pressure.
- 3) We expected to reduce cavitation phenomenon by increasing a certain amount of loss head. The vapor volume fraction was widely distributed throughout the downstream of butterfly valve. It can be interpreted that the already formed bubbles passing through cavities of orifice accelerate the water velocity. Thus, it causes rather higher pressure drop though installing orifice in order to reduce the cavitation occurrence.

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