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CFD Works on Occurrence of Cavitation at the Downstream of Orifice

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1. Introduction

One of wide used flowmeter is an orifice flowmeter, which is installed inside pipes as figure 1. Flowrate is converted into by the pressure difference between the upstream and downstream of orifice.

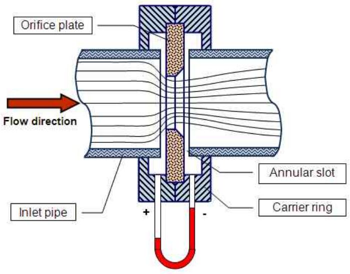


Fig. 1. Schematic Diagram of Orifice Plate

Definition of cavitation is formation of gas bubbles from a flowing liquid in a region where the pressure of the liquid falls below its vapor pressure. Cavitation occurs when a liquid is subjected to rapid changes of pressure by something like orifice, pump suction and discharge or sudden area contraction causing the formation of gas or vapor bubbles in the lower pressure regions of the liquid. [1] During cavitation, vapor bubbles make iterative growth and collapse process damaging pipe and components. Figure 2 shows general 4 step process of cavitation.

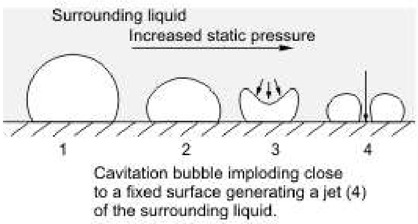


Fig. 2. Four step process of cavitation

There are some codes about installation of orifice for accurate measurement. ASME PTC code is representative. This code requires maintaining the upstream length of orifice plate for assuring that inlet velocity is developed fully. In this context, PTC code published at 1974 was revised at 2004. [2, 3] And PTC code published at 2004 present more conservative requirement. It means criteria on fully developed flow was changed. If flows are not developed fully, the inlet velocity may be distorted and it leads the change of local static and total pressure. Therefore, unexpected results could be occurred such as cavitation, measurement distortion and etc.

In this study, unexpected cavitation by distorted velocity profiles was investigated using commercial CFD code, CFX 13.0.

2. Numerical Method

In CFX 13.0, the Rayleigh-Presset model was implemented as cavitation model. Generally, due to rapid process of cavitation, the assumption of typical thermal equilibrium at the interface could not be applied. In the simplest cavitation models, mechanical effects are only considered ignoring thermal effects. [4]

The governing equation is two fluid model suggested by Ishii [5]. The model is composed of mass and momentum equation for each phase. And each equation has interfacial transfer terms. In this study, homogeneous flow option was selected and the thermal effect was not concerned because it is expected that the amount of mass transfer will be small. The turbulent model is standard k-e model for homogeneous water flow. The boundary conditions are inlet velocity and pressure outlet as inlet and outlet boundary respectively. And for 2D simulation, symmetry boundary condition was applied to surfaces along the y-axis.

3. Results

To assure reliability and accuracy of numerical calculation, mesh size and convergence criteria was investigated. Figure 3 shows grid generations which have 3 different sizes for optimization. All meshes are hexagonal mesh with constant size except region of orifice which has denser meshes and inflation meshes were inserted at the wall.

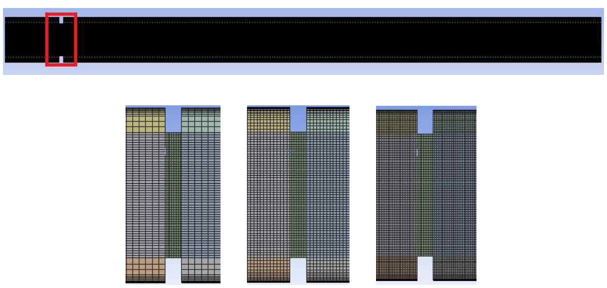


Fig. 3. Grid generations near orifice plate

According to guidelines for cavitation analysis, for good convergence, it should be calculated after preliminary calculation under the condition without cavitation was performed in advance. As iteration number increases, local static pressure, mass residual and momentum residual had enough convergences especially below 10^{-6} of residual value. As shown in table 1, the variables go to a certain constant value with the increase of mesh size. To consider the efficiency and accuracy of calculation at the same time, case 2 was selected as a reference mesh.

Table 1 Calculation results about different grids

	Mesh Number	Local Velocity	Local Pressure	Pressure Drop
Case 1	18950	1.739	45.40	30.07
Case 2	55560	1.746	43.35	28.13
Case 3	153375	1.749	42.61	27.07

Generally, possibility of cavitation is higher at low cavitation number. Therefore, when local velocity is fast and local pressure is low, cavitation tends to occur well. Figure 5 shows the occurrence of cavitation with increasing of average velocity. As the velocity increases, the gas vapor is increased near the wall of orifice and the vapor is extended along the velocity direction and cavitation occurs inside the region of secondary flow.

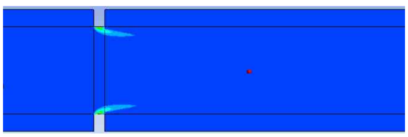
(a) Low Velocity

(b) Medium Velocity

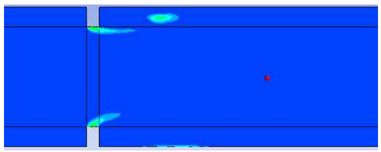
(c) High Velocity

Fig. 5 Contours of void fraction with increasing of average velocity

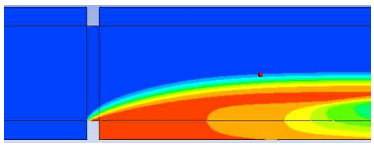
If inlet velocity has inclination, the region of cavitation is mostly distributed at the one side of pipe wall and void fraction also is intense due to the biased mass flow rate as shown in Figure 6.



(a) Zero Velocity Inclination



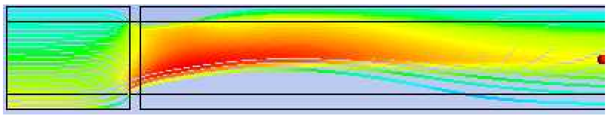
(b) Medium Velocity Inclination



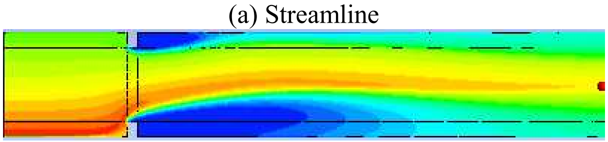
(b) High Velocity Inclination

Fig. 6 Contours of void fraction with increasing of velocity inclination

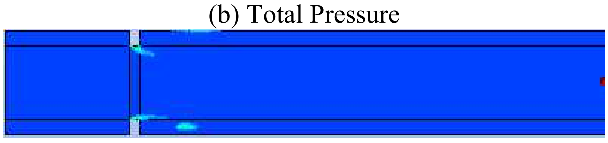
In figure 7, the contours of local pressure and velocity were also matched with void fraction. It shows that if the orifice is installed at wrong position, possibility of the occurrence of cavitation is enlarged.



(a) Streamline



(b) Total Pressure



(c) Vapor Void Fraction

Fig. 7. Velocity, total pressure and void fraction of upstream and downstream of orifice plate

4. Conclusion

When inlet velocity has distorted profiles, unexpected cavitation was investigated using commercial CFD code, CFX 13.0. As the velocity increases, the gas vapor is increased near the wall of orifice and the vapor is extended along the velocity direction and cavitation occurs inside the region of secondary flow. If inlet velocity has inclination, the region of cavitation is mostly distributed at the one side of pipe wall and void fraction also is intense due to the biased mass flow rate. If the orifice is installed at wrong position the possibility of the occurrence of cavitation is enlarged.

REFERENCES

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