Journal of Solid and Fluid Mechanics (JSFM), 13(6): 1-3, 2024

Shahrood University of Technology

Journal of Solid and Fluid Mechanics (JSFM)

DOI: 10.22044/jsfm.2024.12890.3718

Manufacturing Engineering of Iran

Experimental and numerical study of V-Cone flowmeter with continuous nose in single phase liquid flow

Hesam Jazirian[1], Farzad Jafarkazemi[2, *], Hamidreza Rabieefar[3]

[1] PhD, Department of Mechanical Engineering, South Tehran Branch, Islamic Azad University, Tehran, Iran

[2] Emeritus Associate professor, Department of Mechanical Engineering, South Tehran Branch, Islamic Azad University, Tehran, Iran

[3] Faculty Member, Department of Civil Engineering, South Tehran Branch, Islamic Azad University, Tehran, Iran

*Corresponding author: f_jafarkazemi@azad.ac.ir

Received: 03/28/2023 Revised: 10/17/2023 Accepted: 12/26/2023

Abstract

With increasing importance of measurement in industries, especially in petrochemical and water and wastewater, and their need to reduce the installation space and increase the accuracy, it is necessary to improve the existing flowmeters and produce new types. In the last two decades, the V-Cone flowmeter has received the special attention of researchers with features such as reducing the required initial length, lower pressure drop compared to other types, and the ability to be used in two-phase flows. But one of the things that is less discussed is how to connect the flowmeter stand to the body (flowmeter nose). Therefore, in this research, study of a new case that has a continuous nose, have been done. Using test results, correlations were proposed to estimate the pressure drop between two flowmeter sensors and the pressure loss. Calculations showed that the relative error of pressure drop calculation in the range of Reynolds numbers investigated (5.88×10^4 to 9.80×10^4) is about -0.73%. Numerical simulation showed that the continuous type with the highest level of disturbance causes the increase of fluctuations in the value shown by the pressure gauge located downstream and the error in the calculation of the discharge coefficient.

Keywords: Experimental study; CFD; Turbulence modeling; Differential pressure flowmeter; V-Cone

1. Introduction

Considering the increasing importance of flow rate measurement in industries, especially oil, gas and water industries and their need to reduce installation space and increase accuracy, it is necessary to optimize old flowmeters as well as produce new types. For this purpose, the concept of V-Cone flowmeter was presented by researchers [1]. In the last two decades, this pressure differential flowmeter has received the special attention of researchers with its features such as reducing the required initial length and lower pressure drop compared to other types, as well as its ability to be used in two-phase flows.

Singh et al [1] experimentally investigated the performance of a conical flowmeter in different diameter ratios as a function of Reynolds number. They showed that the discharge coefficient in this type of flowmeter is almost independent of the Reynolds number. Nasiruddin et al [2] numerically investigated the effects of using a semi-ellipse at the end of the V-Cone flowmeter. They compared their results for different geometries and at Reynolds numbers 10^1 to 10^6. Nasiruddin et al [3] numerically investigated the effects of Reynolds number and boundary layer thickness on the performance of cone flowmeter. They showed that the discharge coefficient remains almost constant at Reynolds numbers above 4000. Also, the thickness of the boundary layer does not affect the performance of the flowmeter in most cases. Nasiruddin et al. [4] experimentally analyzed wafer cone flowmeter. For this purpose, they used the particle tracking method. According to the results obtained, the discharge coefficient in this type of flowmeter at different vertex angles is independent of the value of the equivalent diameter ratio.

As seen in the previous researches, one of the important points in the design and construction of the V-Cone flowmeter is the optimization of its geometry. In this context, one of the things that is less discussed is how to connect the flowmeter base to the body (the shape of the flowmeter nose). Therefore, in this research, experimental and numerical study of a new sample that has a continuous nose has been carried out.

2. Experimental study of the flowmeter

Figure 1 shows the cone flowmeter under investigation. To calibrate the flowmeter, the discharge coefficient was calculated in the range of Reynolds numbers from 5.88×10^4 to 9.80×10^4. For this purpose, the pressure drop between two sensors is measured using a differential pressure transmitter. Then, by placing this value and the flow rate measured by the master flowmeter (electromagnetic meter) into the proper relations [5], the value of the discharge coefficient is calculated. It can be seen that the changes in the value of this coefficient are small and are in the range of 0.816 to 0.828. Therefore, by comparing the average value of (0.821) with the value presented in ISO 5167-5 [5] (0.82), it can be concluded that the present cone flowmeter, although geometrically different from the flowmeters mentioned in ISO 5167-5 [5], has provided similar performance.

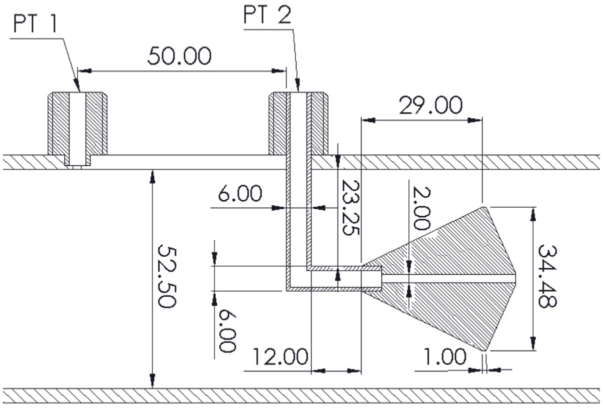


Figure 1. Geometry of continuous nose V-Cone flowmeter (all dimensions are in mm)

Considering the changes in pressure drop in terms of dynamic pressure, equation 1 is proposed to estimate the pressure drop (in kPa) in the V-Cone flowmeter. This equation can be used in times when there is no access to suitable pressure gauges to measure the pressure drop or in cases where a conical flowmeter is used as a mixer.

$$\Delta p_{cone} = 3.0603\frac{\rho {v_{ave}}^2}{2} + 0.0448 \tag{1}$$

The calculations showed that the relative error of relation 1 in the range of Reynolds numbers investigated (5.88×10^4 to 9.80×10^4) is about -0.73%.

According to ISO 5167-5 [5], equation 2 is used to estimate the pressure loss (pressure drop between 1D upstream and 6D downstream of the flowmeter).

$$\Delta p_{loss} = (1.09 - 0.813\beta)\Delta p_{cone} \tag{2}$$

Using equation 2, the pressure loss will be in the range of 0.94 to 2.55 kPa. Therefore, relation 3 is suggested by combining correlations 1 and 2 to calculate this quantity.

$$\Delta p_{loss} = 1.46\frac{\rho {v_{ave}}^2}{2} + 0.0214 \tag{3}$$

3. Numerical modeling

Since experimental researches have limitations that it is very costly or impossible to observe and determine some characteristics of the flow such as the velocity field, turbulence parameters, flow structures, etc., it is necessary to pay attention to numerical studies. For this purpose, in this paper, the numerical solution is performed along with the experimental investigation. The numerical simulation steps are described below.

3.1. Physical model

Different geometries of conical flowmeter including continuous nose, point, curve and elbow were drawn in Solidworks software. In all cases investigated, according to the researches of Nasiruddin et al. [3] and Jazirian et al. [6], the upstream length of the flowmeter is 5D and the downstream length is 30D.

3.2. Governor equations

In order to simulate the three-dimensional single-phase flow, according to relations 4 to 7, the governing equations including continuity and momentum are used along with the equations of the k-ω SST turbulence model.

$$\frac{\partial \bar{u}_i}{\partial x_i} = 0 \tag{4}$$

$$\bar{u}_j\frac{\partial \bar{u}_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial \bar{p}}{\partial x_i} + g_i + \frac{\partial}{\partial x_j}\left(\upsilon\frac{\partial \bar{u}_i}{\partial x_j} - \overline{\acute{u}_i\acute{u}_j}\right) \tag{5}$$

$$\frac{\partial \bar{u}_j k}{\partial x_j} = \frac{1}{\rho}\frac{\partial}{\partial x_j}\left[(\mu_l + \sigma_k\mu_t)\frac{\partial k}{\partial x_j}\right] + \frac{1}{\rho}(P_k - \beta^*\omega k) \tag{6}$$

$$\frac{\partial \bar{u}_j \omega}{\partial x_j} = \frac{1}{\rho}\frac{\partial}{\partial x_j}\left[(\mu_l + \sigma_\omega\mu_t)\frac{\partial \omega}{\partial x_j}\right] + \frac{2(1-F_1)\sigma_{\omega 2}}{\omega}\frac{\partial k}{\partial x_j}\frac{\partial \omega}{\partial x_j} + \frac{\gamma}{\mu_t}P_k - \beta\omega^2 \tag{7}$$

3.3. Boundary conditions

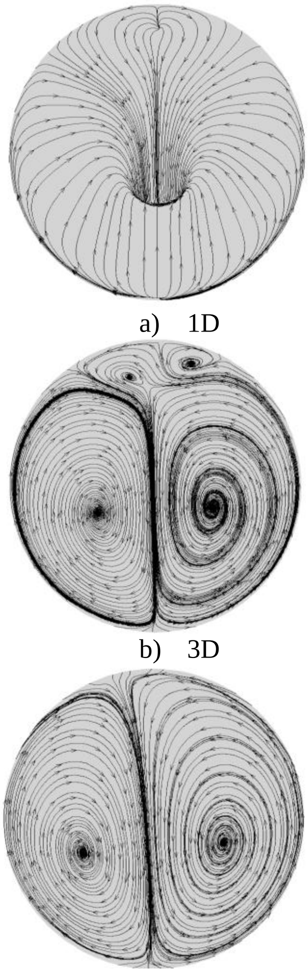
The boundary conditions are listed in Table 1.

Table 1. Boundary conditions

ZONE	BCS
INLET	Power law
OUTLET	Outflow
PIPE WALL	Wall
FLOWMETER	Wall

4. Results and Discussion

Figure 2 shows the development process of transverse flow structures. As can be seen, at the beginning and at a distance of 1D from the end of the flowmeter, the flow hits the cone, causing the transverse flow lines to deviate. After passing the distance 3D, this deviation has caused two large vortices in the lower part and two small vortices in the upper part of the tube. After traveling the distance 6D, the large and small vortices on the left and right side of the pipe are merged and after that, there is no change in the structure of the vortices. Therefore, it can be said that the current V-Cone flowmeter (continuous nose) in the fully developed flow state has created two asymmetric vortices in the y-z plane. Due to gravity, these vortices tend towards the bottom of the pipe and their size is more on the right side of the tube.



a) 1D

b) 3D

c) 6D

Figure 2. Flow streamlines in the y-z plane and for Re=9.2×10^4

5. Conclusions

In this research, the experimental and numerical study of a new sample of a V-Cone flowmeter with a continuous nose has been discussed. For this purpose, the sample under investigation was first calibrated in the Mahmood Abad Metering and Proving Laboratory and the value of the discharge coefficient was determined. Then, the flowmeter was numerically simulated in the Fluent software and the results were compared with the experimental data. Finally, in order to determine the optimal shape of the nose, the numerical solution was repeated for other geometries mentioned in the ISO 5167-5 [5], including pointed, curved and elbow. The results are:

1. Experimental relations were presented to estimate the pressure drop between two flowmeter sensors and the pressure loss. Calculations showed that the relative error of pressure drop calculation in the range of Reynolds numbers investigated (5.88×10^4 to 9.80×10^4) is about -0.73%.
2. Curved geometry with the least increase in turbulence will have the most accuracy in calculating the discharge coefficient compared to other investigated cases.
3. The continuous nose V-Cone flowmeter in the fully developed flow state has created two asymmetric vortices in the y-z plane. These vortices are more inclined towards the bottom of the pipe due to gravity and their size is more on the right side.

6. References

[1] Singh SN, Seshadri V, Singh RK, Gawhade R (2006) Effect of upstream flow disturbance on the performance characteristics of a V-Cone flowmeter, *Flow Meas. Instrum.* 17(5): 291-297

[2] Nasiruddin Sheikh, Singh SN, Veeravalli SV, Hegde S (2019) Shape optimization of the cone body for the improved performance of the V-cone flowmeter: A numerical study. *Flow Meas. Instrum*. 66: 111-118

[3] Nasiruddin Sheikh, Singh SN, Veeravalli SV, Hegde S (2020) Effect of Reynolds number and boundary layer thickness on the performance of V-cone flowmeter using CFD. *Flow Meas. Instrum*. 73: 101728

[4] Nasiruddin Sheikh, Singh SN, Veeravalli SV, Hegde S (2020) Flow characteristics of back supported V-cone flowmeter (wafer cone). *Flow Meas. Instrum*. 73: 101750

[5] *ISO 5167-5*, Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full - Part 5: Cone meters, First ed., 2016.

[6] Jazirian Hesam, Jafarkazemi Farzad & Rabieefar Hamidreza, Numerical Evaluation of V-Cone Flowmeter Performance in Axisymmetric & 3-D Coordinates, *5th Iranian Flow Measurement Conference & Exhibition*, (In Persian), July 2022