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STUDY OF FLOW PERFORMANCE OF A GLOBE VALVE AND DESIGN OPTIMISATION

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Abstract

Valves control the fluid flow and pressure in a system or a process. Globe valves have good throttling ability, which permits its use in regulating flows. Detailed understanding of flow in Globe valve with cage apertures of various shapes and its impact on the flow characteristics and optimization was carried out. The computational study was carried out using FLUENT, a finite volume based code. Grid sensitivity test were done and the results validated experimentally. The effect of aperture configuration on flow characteristics and valve coefficient was studied to arrive at optimum value. Valve coefficient was found to be dependent on aperture shape and is maximum for the valve with triangular shaped aperture. Methodology to improve flow performance of a globe valve with highest valve coefficient is established.

Keywords: Valve coefficient, Globe valve, Caged, Throttling.

1. Introduction

Valves types generally in use are gate, plug, ball, butterfly, check, pressure-relief, and globe valves. Globe valve is a control valve and is used to throttle efficiently. Seating is parallel to the line of flow and the change in direction of fluid flow through these valves produces increased resistance and considerable pressure drop. Globe valves are also recommended for services requiring frequent operation and positive shutoff. Merati et al. [1] investigated the flow around a V-sector ball valve. Huang and Kim [2] simulated turbulent flows in a butterfly valve using FLUENT, in which the k-ε model was employed for turbulence modelling. Miller and Stratton [3] explained the criterion which involves limits on the fluid kinetic energy exiting through the valve throttling area.

Chern and Wang [4] investigated the effects of V-port on the volume flow rate and

Nomenclatures

C_v	Valve coefficient
D	Diameter of the pipe, m
D_p	Differential pressure, bar
ε	Energy dissipation rate, m^2/s^3
G	Specific gravity
k	Turbulent kinetic energy, $kg.m^2/s^2$
Q	Flow rate , m^3/hr
Re	Reynolds number

Abbreviations

ANSI	American National Standards Institute
ISA	International Society of Automation
ISO	International Organization for Standardization

flow features, 3-D numerical simulations and experiments were conducted to observe the flow patterns and to measure performance coefficients when V-ports with various angles were used in a piping system. Sreekala and Thirumalini [5] have carried out noise evaluation and experimental validation in globe valves using FLUENT for flow performance study. Cage design decides the flow performance of the caged type globe valves. The significance of aperture shape on valve performance was not reported earlier. Hence studies related with caged type globe valves having different configurations are useful for improving their flow performance.

In the present investigation, Globe valve with different cage configurations and throttle positions are modelled to find out the valve coefficient, pressure and flow performance inside and outside the cage and is validated with experimental results.

2. Numerical Simulation

A 2 inch Globe valve with five different cage configurations is modelled. Flow medium is water at standard conditions and 3D steady incompressible flow solver of FLUENT is used for flow simulation. All geometries are modelled using GAMBIT. Cages with eight circular, rectangular, triangular and elliptical apertures are modelled and simulated for different differential pressures and flow rates. Iterations were carried out and the residual value considered for convergence of continuity and momentum equations was 0.0001.

Figure 1 shows a portion of the computational flow domain for 100 percent opening of the valve with cage having circular apertures. Computational domain of the valve is extended upto 10D (D is diameter of pipe) upstream and 15D downstream of the valve to get developed flow at both ends. Pressure inlet and pressure outlet boundary conditions are used. No slip boundary conditions are applied at the walls. Grid independence test was done with grid sizes 0.005 m, 0.0015 m and 0.001 m cells. For the grid sizes 0.0015m and 0.001m, it was found that there was no variation in C_v value under the same geometry and flow conditions. Hence grid size of 0.0015m was finally chosen. Figure 2 shows the mesh model of the valve.

For turbulence modelling RNG (Renormalization Group) k-ε turbulence model is used. RNG Model follows the two equation model and is derived from the fundamental governing equations for fluid flows using Renormalization Group (RNG) theory. As compared to standard k- ε model an additional term is added to the ε equation Yakhot, et al. [6]. This term changes dynamically with the rate of strain of turbulence, providing more accurate predictions for flows with rapid distortion and anisotropic large-scale eddies. Applications of the RNG k- ε model to a number of complex flows such a separated flows have also yielded excellent results in cases where standard k- ε model predictions have been unsatisfactory. Hence RNG k- ε turbulence model was considered for the present analysis.

The cage configurations are simulated at various differential pressures and valve coefficient (C_v) values are evaluated for comparison. Eight apertures are arranged in two rows in zigzag manner in all cages. The area of the flow passage is fixed for all cases as 0.000346185 m^2. Figure 3 indicates the flow rate (Q) with the differential pressure (D_p) measured at 2D upstream and 6D downstream of the valve at full opening condition. From Fig. 3, it is clear that for the same differential pressure (D_p), flow rate is maximum for valve with cage configuration having triangular shaped flow passage and it possesses maximum C_v values. The C_v values for all the four configurations are indicated in Table.1. Also C_v value for all cases are plotted in Fig. 4. From Fig. 4, it is clear that for a particular Reynolds Number, differential pressure is minimum for valve having triangular shaped cage and hence it can be used for higher flow rates as compared to the others.

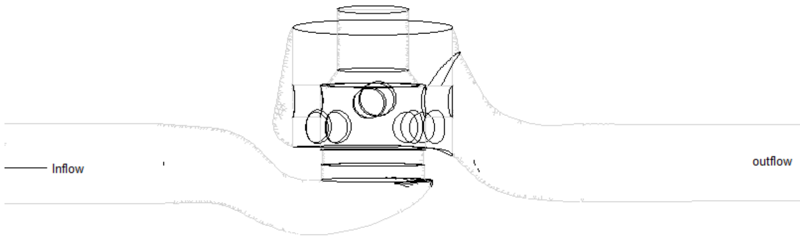

Fig. 1. Valve domain.

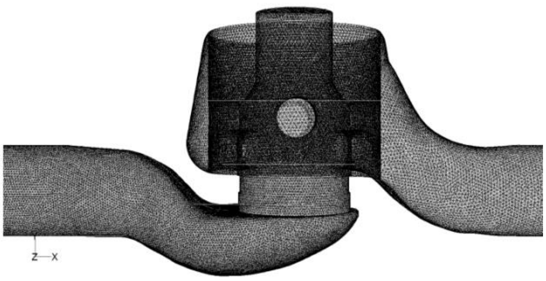

Fig. 2. Mesh model.

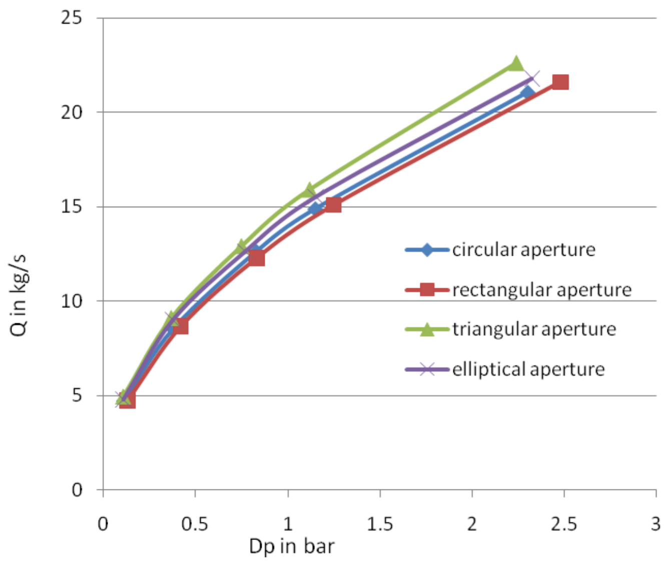

Fig. 3. Variation of different pressure D_p with flow rate Q.

Table 1. C_v values for various configurations.

Case no.	Aperture shape	C_v (full opening)
1	Circle	57.8
2	Ellipse	60.4
3	Rectangle	56.2
4	Triangle	62.5

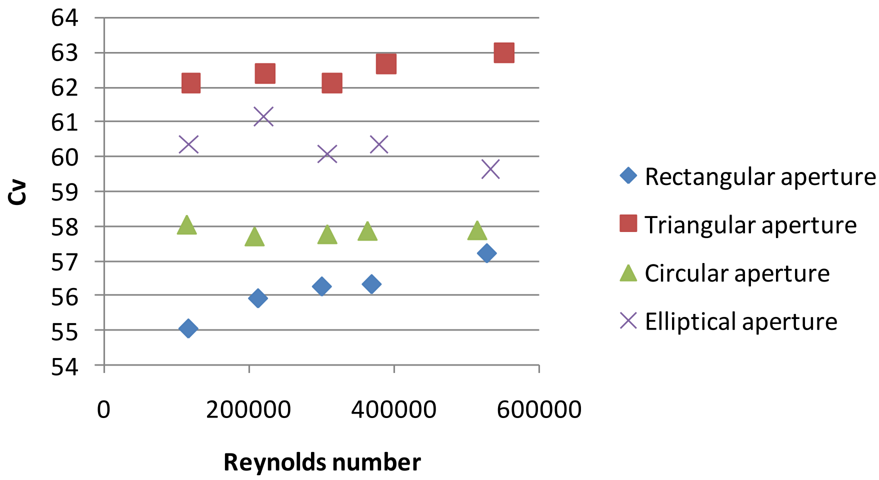

Fig. 4. The relation of Reynolds number with valve coefficient.

3. Experimental Validation

The valve was installed in the test line as indicated in Fig. 5, which shows the Schematic of test setup.

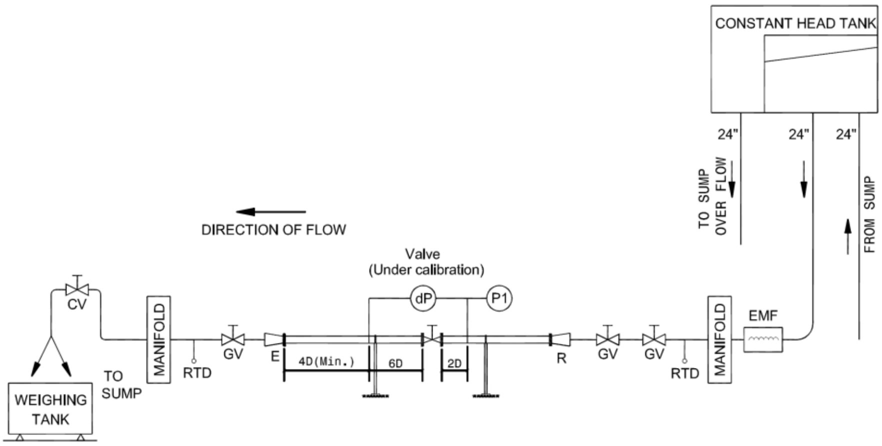

Fig. 5. Schematic diagram of experimental setup.

The line was flooded and entrapped air was cleared using circuit air bleeds. The valve was set at the fully open position. The downstream control valve was set to give the desired pressure differential across the test valve, which was measured using high precision differential pressure transmitters. When flow conditions stabilized, the flow rate was measured using the reference flow meter and differential pressure across the valve was also noted. Upstream pressure and temperature were also recorded. Instrumentation details are given in Table 2. The following standards are referred

ISO 4185-1980: Measurements of Liquid flow in closed conduits using weighing method”

ANSI/ISA 75.02-1996: Control Valve Capacity Test Procedure

ANSI/ISA 75.01.01-2002: Flow Equations for Sizing Control valves

Table 2. Instrumentation details.

Instrument	Parameter	Range	Unit	Uncertainity	Readability
Pressure Gauge	Pressure	16	bar	1.49E-01	1.00E-01
RTD	Temperature	10-49.8	°C	1.30E-01	1.00E-02
Densitymeter	Density	3000	kg/m^3	7.00E-02	1.00E-03
Data Acquisition System	Current	4-20	mA	1.02E-02	1.00E-05
Magnetic Flowmeter 4''	Flow rate	300	m^3/h	9.44E-02	1.00E-02
Magnetic Flowmeter 2''	Flow rate	60	m^3/h	1.62E-02	1.00E-02
DpTransmitter	D_p	20000	mbar	6.755E+00	1.00E-05
DpTransmitter	D_p	5000	mbar	1.26E+00	1.00E-05
DpTransmitter	D_p	1000	mbar	4.00E-01	1.00E-05
DpTransmitter	D_p	500	mbar	2.00E-01	1.00E-05

At each opening, flow rate was measured at three differential pressures, 0.9 bar, 0.5 bar and 0.1 bar and the procedure was repeated for each valve opening. Test was conducted at openings varying from 10% to 100% at an interval of 10%. At each opening, valve coefficient (Cv) was found for various differential pressures using the Eq. (1)

$$C_v = 1.156Q\sqrt{\frac{G}{D_p}} \tag{1}$$

where Q is the flow rate (m^3/hr), G is specific gravity and D_p is differential pressure across the valve (bar). Temperature of water was noted during each test using on-line Resistance Temperature Detector (RTD) with sensitivity of 0.01°C. The line pressure was measured using a precision pressure gauge with precision of 0.01bar and density of water was obtained from an on-line Densitometer with 0.001 kg/m^3 precision. The C_v curve for the valve at ten openings are as indicated in Fig. 6, which validates the computational results with experiment. Experimental and computational results are compared in Table 3. % Error with respect to experimental results were evaluated and was found to be less than 9% for all cases

Table 3. Comparison of results.

%opening	C_v – Expt.	C_v- CFD	% error
100	55.28495	58.45004	5.725038
90	54.75	55.95	2.191781
80	52.3	56.3	7.648184
70	50.5	54.5	7.920792
60	49.6	52.38	5.604839
50	46.8	50.5	7.905983
40	41.5	45.01	8.457831
30	30.68	33.14	8.018253
20	16.44	17.7	7.664234
10	6.17	6.7	8.589951

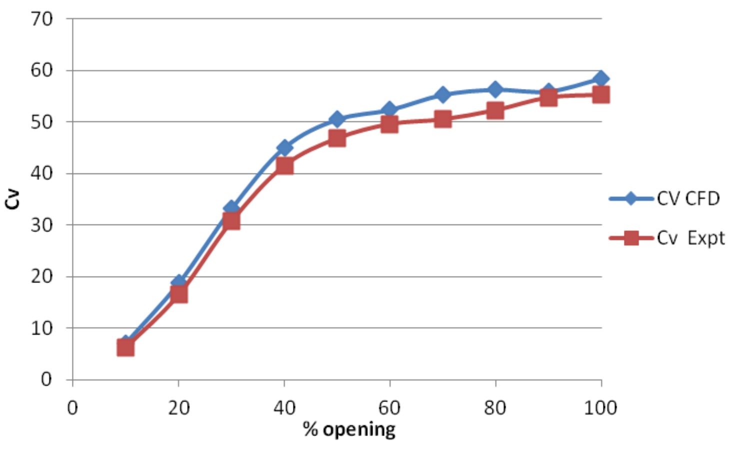

Fig. 6. Relationship between experimental and computational C_v.

4. Results and Discussion

Computational analysis was carried out for valve with four types of flow passage geometries at different openings and hence different flow rates. Figure 3 indicates the comparison of flow rates at 100 % opening of the four types of flow passages considered. Figure 6 shows the experimental C_v values and comparison with computational results. % Error with respect to experimental results are evaluated and was found to be less than 10% for all cases. It was also observed that C_v values were found to vary when the aperture shape was altered. C_v value was found to be the least for cage with rectangular flow passage and highest for cage with triangular flow passage as shown in Fig. 4. Also Fig. 4 indicates that for the same flow rates, differential pressure is minimum for valve having triangular aperture and hence it can be used for higher flow rates as compared to the others. The minimum absolute pressure inside the cage under similar flow conditions is maximum for valve having triangular aperture. Hence maximum velocity attained inside the cage under similar flow conditions is least in this case and which indicates better flow performance characteristics as compared to other cases. The present work can be further extended with modifications in the area and number of cage aperture configurations to understand the flow characteristics and to choose the one with best flow performance.

5. Conclusions

Flow characteristics of the globe valve were predicted using Computational analysis. Both computational and experimental analyses were carried out for valves with different cage configurations. Computational results were compared with experimental results and it was found to be in good agreement. After simulation it was found that the performance of the valve with triangular aperture was better as compared to other geometries and it possesses the maximum C_v value at the same Reynolds number. Hence valve having triangular aperture with best flow characteristics can be used for higher flow rates as compared to others.

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