Numerical Analysis of Ball Valve Performance for Coefficient of Flow

[1]Akshay B Ravande, [2]D N Jadhav, [3]Tansen Chaudhari

[1,2]Sardar Patel College Of Engineering, Mumbai University of Mumbai
[3]Fluid Controls Private Limited, Bhosari MIDC, Pune,
Email: [1]ak.ravande@gmail.com, [2]tansen.chaudhari@fluidcontrols.com

Abstract: Ball valves are commonly utilized in piping system to control the flow. They are also used for on/off or throttling operations. Valves are specified according to values of their flow coefficient (C_V). C_V for liquid is nothing but volume of the water at 68^0F in US gallons per minute that passes through the valve at pressure drop of 1PSI. In the present work, volumetric flow control of water through valve is done by making different opening of ball ie. 10% to 100% and C_V values with respecting angles are calculated numerically. For calculating the C_V , firstly model of ball valve is prepared by using tool SOLIDWORKS 2014 and also simulations are carried out in SOLIDWORKS FLOW SIMULATION. From results obtained from numerical analysis, it was found that flow rates with different opening angles are proportional and by decrease in pressure drop C_V values for valve are increased. Though the ball valve Cv value is not focused in the past, with recent trends in piping design advancements its being essential to focus these values.

Keywords: Ball valve, Flow coefficient, Coefficient of flow, SOLIDWORKS.

I. INTRODUCTION

Ball valve is device which regulates flow of fluid which may be liquids, gases or fluidized solids by simply rotating the ball. In earlier days ball valves were designed only for hydraulic applications but now they are widely used in instrumentation, pneumatics and also in other fields due to its reliability and capacity to work with high pressure upto 1000 bar. Valve contains floating ball which can be turned with help of handle which allows flow of fluid through it. Floating ball, body, ball seat, handle, spindle and O-rings are main components of valve. Generally components of valve are made up of metal, plastic, or metals with ceramic. Floating balls are plated with chrome which improves durability of ball for longer use. Ball seals are made up of Derlin or PTFE (Polytetrafluroethylene) because it maintain its strength, toughness and flexible with high temperature.

Volumetric flow control of fluid through ball valve is possible by making angle between floating ball and ball seat or body. Capacity of valve is generally indicated by flow coefficient value, higher the value higher is the capacity. Ball valves will perform accurately only if they are sized correctly. Determining flow coefficient values is the first step in sizing process. Now a days performance of ball valve increased due to availability of the flow structure in ball valve. Now it is possible to observe the flow inside the ball valve due to progress in the areas of flow visualization. This flow visualization results gives the vortices formation inside the valve which determines the energy loss or pressure drop which helps to improve the performance of ball valve.

II. LITERATURE REVIEW

Useful information about ball valve design given by the Hutchsion Kirik, Driskell and Pearson[1].José R. Valdés, jsé M. Rodríguez , Raúl Monge , José C. Peña ,Thomas Pütz. Performed number of simulations on ball valve using CFD to determine cavitating flow and also these results were validated experimentally[2].By adjusting the pressure level on the valve output port tests were performed to obtain mass flow rate with different operating conditions and they conclude that correlation between measurements and CFD result is excellent. Jose M. Rodrigues developed methodology for parametric modeling of the flow in different types of hydraulic valves. Dong Soo Kim conducted numerical analysis for strength and thermal shock on high pressure cryogenic valve in order to examine performance characteristics and tested it experimentally[3]. By that testing he concluded, design for different part of the valve such that body, ball and seat is optimized. With help of that testing high pressure cryogenic valve with no leakage was designed. G.Tamizharasi carried out the CFD analysis for symmetric disc valve and concluded that at smaller opening angles pressure loss is less and turbulence at downstream is increases with increase in opening angle[4]. Performance test, flow patterns and cavitation phenomena of ball valve tested by Ming Jyh Chern, Chin-Cheng Wang, Chen Hsuan Ma. With respect to different openings and inlet velocities various flow patterns at inlet and at downstream of ball valve were visualized using particle tracking flow visualization method (PTFV). Also cavitation phenomena studied under certain conditions. The correlation between the valve performance and flow patterns were presented and discussed. This method provides effective way to determine the performance coefficient of valve and understand the condition for the cavitation[5].Measurement of surface pressure distribution was given by the Kelso et al. He also give the balance between the pressure distribution and Reynolds shear stress distribution along the separation stream line [6].

III. ANALYTICAL MODELING

Components of ball valve:

1. Body: It is considered as the principal part of valve because it holds all the other parts. It also serves as the pressure boundary of the valve because it is the first line of resistance against the volume and pressure of the liquid flowing through all the pipes connected to it.

2. Ball: It is the main part of the ball valve which allows the required amount of flow to pass at desired conditions. It is also made from the carbon steel selected by using the ASTM A105. Balls are mirror finished and edges of ball are machined with curvature in order to avoid the wear.

3. Ball seals: Flow through the valve can be controlled by maintaining proper surface contact between the ball and ball seals. They are generally made up of the Delrin or PTFE (polytetrafluroethylene) OR Teflon.

4. Spindle: Spindle is used to connect the ball of the valve and the actuator of valve ie handle . In between the handle and ball number of parts are mounted such as the spindle washer, spindle ring, stopper plate, spring washer, locking ring, hex headed bolt. Spindle o ring is used to avoid leak, they made up of the Teflon.

Cut section along with the components are shown in figure

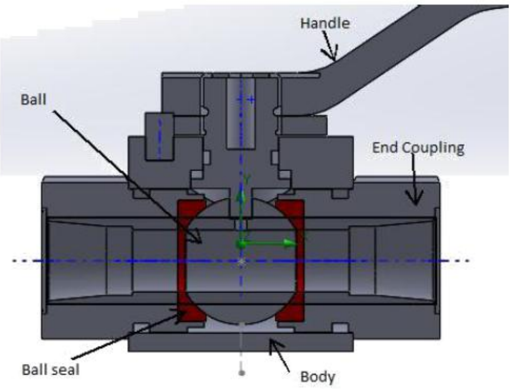

Fig 1. Cut section of ball valve

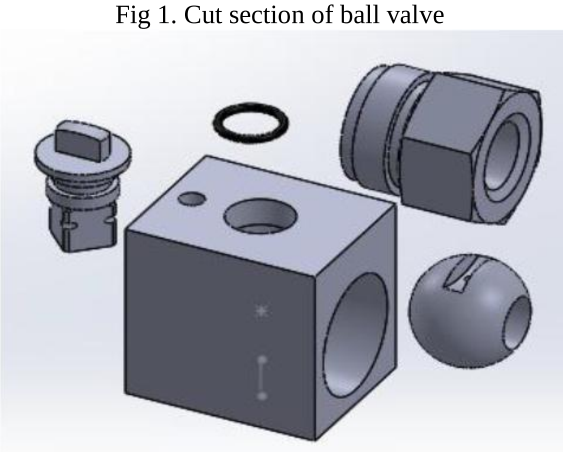

Fig 2. Components of ball valve

Capacity or performance of any valve is given by the flow coefficient values (Cv). Cv of valve is nothing but volumetric flow in US gallons of fluid passing through the valve with 1 minute which maintained at pressure drop of 1PSI. Along with C_v the performance of ball valve also depend on tendency of cavitation. When we fully open the ball valve then pressure loss at the downstream is low suppose the valve is open just 10% then pressure loss at downstream is high if this pressure goes below the vapor pressure of the fluid causes vapor bubble formation and when pressure recovery takes at downstream then these bubbles collapse which causes sound similar as of tumbling rocks in pipe. This cause localized stresses on the walls of valve which results in pitting. In case of ball valve volumetric flow is controlled by providing angle between ball and body which changes the opening for the flow and allows the different volumetric flow. For calculating the Cv value analytically we need to know actual pressures at inlet and at downstream, volumetric flow rate, piping factor and specific gravity of fluid. When we know that all values then Cv value can be calculated as

$$C_v = 1.16 *$$

$$* \sqrt{\Delta}$$

Where Q = Volumetric flow (m^3/h);

ΔP = P1 – P2 (bar);

SG = Specific gravity;

Fp = Piping geometric factor

The above given formula is applicable only for the liquid. As compared to gases which are compressible calculation of Cv for liquid is easy because it is depends only upon the pressure difference between inlet and outlet.

VI. NUMERICAL ANALYSIS

For calculating the Cv of valve firstly the model of ½" ball valve is prepared in SOLIDWORKS 2014. Cut section of ball valve and components are shown in previous figure. For calculating the Cv value of water by numerical method SOLIDWORKS FLOW SIMULATION tool is used. SOLIDWORKS flow simulation is new class of CF (Computational flow dynamics) analysis software that is fully embedded in mechanical design engineering for all application.

Governing Equations

In fluid region SOLIDWORKS flow simulation solves Navier- Stokes equations which are formulations of mass, momentum and energy conservation laws;

$$\frac{\partial\rho}{\partial t} + \frac{\partial(\rho u_i)}{\partial x_i} = 0$$

$$\frac{\partial(\rho u_i)}{\partial t} + \frac{\partial}{\partial x_j}(\rho u_i u_j) + \frac{\partial P}{\partial x_i} = \frac{\partial}{\partial x_j}(\tau_{ij} + \tau_{ij}^{R}) + S_i$$

$$\frac{\partial \rho H}{\partial t} + \frac{\partial \rho u_i H}{\partial x_i} = \frac{\partial}{\partial x_i}\left(u_j(\tau_{ij} + \tau_{ij}^{R}) + q_i\right) + \frac{\partial p}{\partial t} - \tau_{ij}^{R}\frac{\partial u_i}{\partial x_j} + \rho\varepsilon + S_i u_i + Q_H$$

$$H = h + \frac{u^2}{2}$$

For calculating high speed compressible flows and flows with shock waves following equations are used

$$\frac{\partial \rho E}{\partial t} + \frac{\partial \rho u_i \left(E + \frac{P}{\rho}\right)}{\partial x_i} = \frac{\partial}{\partial x_i}\left(u_j(\tau_{ij} + \tau_{ij}^{R}) + q_i\right) - \tau_{ij}^{R}\frac{\partial u_i}{\partial x_j} + \rho\varepsilon + S_i u_i + Q_H$$

$$E = e + \frac{u^2}{2}$$

First step in flow simulation analysis is formation of lids in order to make water tight model and setup the flow simulation wizard along with providing the fluid subdomain. It includes the selection of the units for the boundary conditions, analysis types which includes external or internal flow analysis - in ball valve case we have to do internal analysis for the fluid flow. Boundary conditions for this case of simulation are inlet pressure, outlet pressure and inlet volumetric flow.

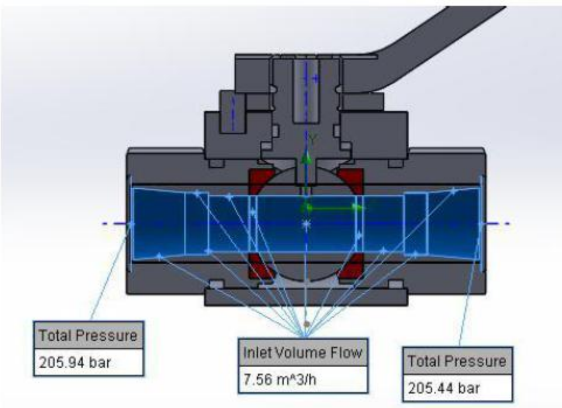

Fig.3 Boundary Conditions

Flow simulation is solved by providing generalized equation goal which is given as,

Results which are obtained at different opening positions (100% open to close) by giving boundary conditions as P1= 205.94 Bar , P2= 205.44.5 bar, Q = 7.5 m^3/h

Opening of valve in%	P_1 (bar)	(bar)	PD (bar)	Q m^3/h	Cv
100% Open	205.939	205.441	0.498	7.56	12.43
80% Open	205.930	205.445	0.494	7.55	12.45
60% Open	205.930	205.443	0.496	7.60	12.43
40% Open	205.941	205.442	0.498	7.56	12.41
20% Open	205.941	205.443	0.4985	7.56	12.42

Table 1. Results of flow simulation

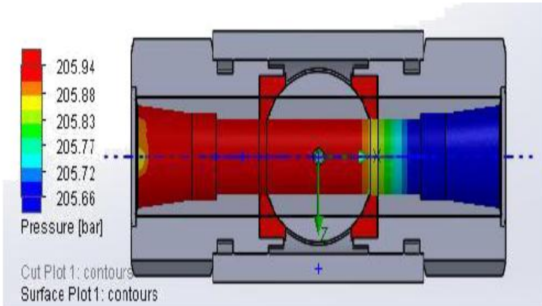

Fig.4 pressure contour for 100% open

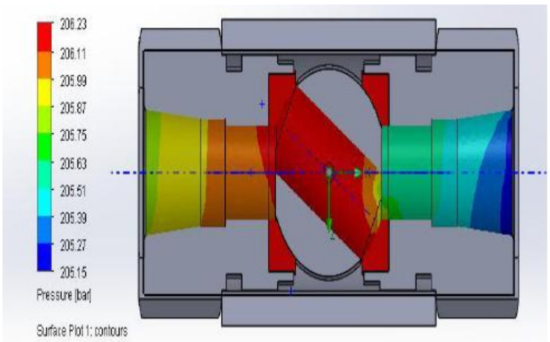

Fig.5 pressure contour for 40% open

Theoretically when valve closes from 100% to 0% Cv values decreases but practically it may not be possible due to cavitation and vortices formation. In the future work these results were checked experimentally by manufacturing experimental setup and results will be validated.

V. CONCLUSION

This paper talks about basics of ball valve along with importance of Cv value and other parameters which need to be considered to study the performance of ball valve. Results for Cv value were calculated numerically by flow simulation and discussed along with their figures. Cv value of valve is depends upon flow conditions. As the opening for flow is small, loss of energy is high due to formation of vortices which results in loss of pressure. Also it may causes cavitation. Hence cavitation is important factor which should be considered while designing of ball valve.

REFERENCES

[1] J.W. Hutchison, ISA Handbook of Control Valves, second ed, Instrument Society of America, Pittsburgh, 1976

[2] Jose R. Valdes, ―Numerical Simulation and Experimental Validation of the Cavitating Flow Through a Ball Check Valve‖, International Journal of ‗Energy Conversion and Management', Vol. 78, 2014, pp. 776-786

[3] Dong-Soo Kim, ―Analysis and Design of Cryogenic Ball Valve, International Symposium On Fluid Power, Toyama‖, 2008

[4] G.Tamizharasi, ―Cfd Analysis Of A Ball Valve In A Compressible Fluid‖, ‗International Journal Of Engineering Trends And Technology', Vol. 3, Issue 2, 2012, Pp. 17-21

[5] Ming-Jyh Chern, Chin-Cheng Wang, Chen-Hsuan Ma, Performance test and flow visulation of ball valve, Experimental Thermal and Fluid Science 31 (2007) 505-512.

[6] R.M. Kelso, T.T. Lim, A.E. Perry, The effect of forcing on the time averaging structure of the flow past a surface-mounted bluff plate, Journal of Wind Engineering and Industrial Aerodynamics 49 (1–3, Part 1)