Validation of Valve Coefficients Using Experimentation and Numerical Analysis

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Abstract. Today's demanding projects calls for a quality valve that is effective in controlling the flow in the closed conduit with optimum flow velocity and least energy losses in the system. Proper selection of valve requires information on maximum and minimum flows and the head loss for wide range of applications. Hence a comprehensive research study was carried out on an improvised tricentric butterfly valve of 100 mm NB over a conventional type of butterfly valve and globe valve at different percentages of openings to determine the flow performance characteristics at CWPRS, Pune. These studies highlight the improved performance of the tricentric butterfly valve over the conventional valve. The findings exhibit the exceptional performance and advantage of equal percentage flow control loop characteristics of a new tricentric valve over the conventional type S-shape flow performance characteristic curve and the linear characteristics of the globe valve. The tricentric valve has demonstrated in the opening range between 15° and 75° showing an equal percentage characteristic. The minimal pressure drop in these valves, causes significant energy savings over a broad range of control applications like water distribution systems, power generation, refineries, chemical, and desalination. The validation by experimental data with CFD is obtained with reasonable near-optimum results for valve coefficients.

1 Introduction

An essential function of a control valve in a closed conduit is to open, throttle and close the rate of flow. The throttle characteristics of a valve may be quick opening, linear or equal percentage controlling of flow. As such, above inherent characteristic of control valve plays a vital role in process control engineering [1]. Proper selection of a control valve for a particular application may impact on economic consequences and efficiency of the system [2, 3]. Proper size and control characteristic of a valve will have impact on the optimum flow passes through the closed conduits irrespective of operation on pneumatic or electrical [4]. Butterfly valves, ball valves and plug valves are frequently used as on/off and throttling services with negligible pressure and energy losses [5]. Butterfly valves and globe valves are used in large sizes for handling larger flow of liquids, liquids with suspended solids in water treatment, waste water, chemical applications and fire protection systems [6, 7]. Additional advantages of the butterfly valve are comparatively high coefficient of flow (Cv), standard face to face dimensions and their availability in chemically resistant materials. The butterfly valve is
considered a high recovery valve with less head loss across the valve. Hence, the size of the required pump is reduces and considerably implies cost saving on the project. Hence various researchers [8, 9] have carried out studies on butterfly valve characteristics. However, the disadvantages of the butterfly valve are not bubble tight due to the erosion and pitting when used for slurry applications. Butterfly valves are good control limited to 60° opening and it is subjected to frequent wearing out of seals. Noting the number of advantages of butterfly valves, R&D efforts have been made recently to overcome most of the disadvantages of these valves by introduction of “Tricentric butterfly valves”. The paper highlights the improvised performance of the new tricentric butterfly valve which was established in high precision test facility at CWPRS, Pune. Comparison of flow performance of this new valve with conventional valves indicates the superiority achieved by the new valve design in respect of flow characteristics. The study is to verify and validate CFD analysis [10, 11] to obtain reasonable results for control valve coefficients. The steady and incompressible Navier-Stokes equations are solved numerically to predict the flow behavior and compute the pressure loss and flow coefficients. A limited research has been focused on the validation of experimentation and CFD analysis. Hence, a comprehensive 3D simulation study is carried on 4" (100 DN) butterfly valves and globe valves is conducted to establish a trusted and a calibrated numerical solution model after comparing with experimental data.

1.1 Valve Performance Coefficients
The principal use of valve performance coefficients is to assist within the selection of appreciated valve size for a specific application. All the relevant sizing factors must be known at different valve disk angles (α), valve performance coefficients include pressure loss and flow coefficients. The characteristics of the valves are generally obtained experimentally or alternatively by using CFD.

1.2 Flow coefficient
The flow coefficient Cv flow per hour passes through a valve with a head loss of 1 bar and can be calculated by:

\[ \text{Flow coefficient } C_v = \frac{Q}{\sqrt{\Delta P/SG}} \]  

1.3 Pressure loss coefficient
The pressure loss coefficient, K, is a dimensionless and generally used to predict the minor head loss. Thanks to the presence of valve in fluid flow field, it is important to get the valve pressure loss coefficient as a function of valve disk angle (α). Two different methods are used numerically to analyze.

\[ \text{Loss coefficient } K = \frac{2\Delta P}{\rho V^2} \]  

ΔP - Pressure difference in (bar)
Q - Flow rate in (m^3/hr)
SG - Specific gravity
ρ - Water density (kg/m^3)
V – Fluid velocity (m/sec)

2 Experimental Test Circuit
The high precision test facility at CWPRS is used for assessment of hydraulic performance of various flow elements (Fig.1). The circuit equipped with volumetric tank for accurate measurement of flow volume. The test valve is installed in piping circuit by providing required upstream and downstream straight lengths. The service pumps of the circuit pump the stabilized flow passes through the test specimen. The differential head across the test valve is measured by pre-calibrated pressure transducers whereas each set of flow rate is measured volumetrically.
2.1 Instrumentation
The details of instruments used, and their accuracies are as follows:

Flow: ±0.3 % by volumetric method
Head: ±0.1% by manometer
Time: Digital timer with 0.001 second least-count
Flow stability: Set flow rate of 0.001 % accuracy

3. Experimental Findings
The head loss values were measured for different flow rates with different percentage openings of valves viz., 100 mm NB (tricentric) and 100 mm NB (conventional) butterfly valves and 100 mm NB globe valve. The values of inlet velocity through the test valves were ranging from 0.25 m/sec to 3 m/sec with the various valve opening positions. The loss coefficients (K) and flow coefficient (Cv) were computed from the observation made during the test. Table: 1-3 illustrate the experimental findings and CFD in respect of the valves. To compare the relative performance of these valves, graphs indicating flow characteristics VS percentage of valve openings are plotted.

4. Computational Fluid Dynamics
For doing the flow analysis of this model, there is a requirement of a CFD tool. For this work, ANSYS Fluent CFD tool was used to model the valve. In CFD analysis, numerical methods and algorithms are used to solve and analyse problems with fluid flow with governing equations and the boundary conditions as specified.

4.1 Methodology
The assembled file from CAD software is modeled into IGES and into design modeler. The fluid domain created, took the form of the whole void. The meshed volume of fluid domain is as shown in Figure 2-4. The optimum gap between the trim surface and valve seat had a very fine mesh which was necessary to capture accurately the flow through that narrow region. The CFD code utilized in Fluent is usually based on Finite Volume technique wherein a complex geometry can be divided into a finite region of control volume and the mass and momentum conservation equations are applied to each control volume.

4.2 Mesh Generation
The steps in CFD simulation are pre-processing, solving, and post-processing. The studied flow volume including the valve disc and the connected pipes has meshed via ANSYS. The generated mesh has been repeated for alternate mesh types and sizes, the efficient mesh method for converging solution is executed using unstructured (tetrahedral). An illustration of the geometry and mesh is shown in (Figs. 2-4) with a locally re-fined numerical grid of high-density ranged from 0.8x10^6 to 1.2x10^6 elements. The model previously described is implemented directly into Ansys18.2 Partial
differential equations are discretized into a system of algebraic equations and these algebraic equations are then solved numerically over each elemental discrete volume.

4.3 Boundary Conditions
Sample boundary conditions for conventional butterfly valve at 11% opening are as follows.
Set up of the case (Common):
1. Time: Steady state
2. Pressure Based solver
3. Gravity: 9.81 m/s² in -z direction
4. Viscous Model: K epsilon, Realizable with Scalable Wall functions.
5. Material: Water
6. B.C: Pressure inlet: 200 kPa
   Pressure outlet: 100.46 kPa
7. Standard initialization: Computed from inlet.

4.4 CFD Modeling and Simulation
A 100 NB conventional butterfly valve, globe valve, and tricentric valve, along with other internal parts and alternate types of trim shapes were modeled in Solidworks as shown in figure 5-7. Flow analyses are carried out on the stem and bush of each plug.

5 Results and Discussions
The performance of CFD results for flow coefficients and pressure loss coefficients are given in table 4-6. The velocity contours are given in figure 8. The comparative results of flow coefficients, pressure loss coefficients of butterfly valve, globe valve and tricentric valve are given in graphs.
5.1 Velocity Contours

![Velocity Contours](image)

**Fig 8.** Velocity contours of various positions of different valves

CBV – Conventional Butterfly Valve  
GV – Globe Valve  
TBV – Tricentric Butterfly Valve

Table: 1-3 illustrate the experimental findings and CFD in respect of the valves. To compare the relative performance of these valves, graphs Indicating flow characteristics VIS percentage of valve openings are plotted.
Table 1. Characteristic coefficients of 100 mm NB tricentric butterfly valve Exp. and CFD

| Flow rate (m³/hr) | Differential Pressure (bar) | Valve Opening (%) | Valve Coefficient (Cv) | Loss Coefficient (Kv) | % Flow Coefficient (%Cv/CvMax) |
|------------------|----------------------------|-------------------|------------------------|-----------------------|-------------------------------|
| 10.558           | 1.00186                    | 10                | 206.348                | 2.9110                | 100.000                       |
| 20.506           | 2.174175                   | 10                | 193.836                | 2.104802              | 100.000                       |
| 53.799           | 1.00186                    | 55                | 74.338                 | 77.139                | 100.000                       |
| 82.194           | 1.00186                    | 66                | 82.194                 | 120.166               | 84.534                        |
| 206.126          | 1.00186                    | 100               | 206.512                | 1.80540               | 100.000                       |

The comparative valve coefficients with experimental and CFD results are given in graphs below.
A comparison of flow performance curves of these valves indicates that the tricentric valve besides the advantage of perfect sealing also exhibits an equal percentage of flow control loop between openings 15° and 75°. Therefore this valve provides a precise throttling through the lower range and can be used effectively for pressure control purposes. From the performance curve of a conventional butterfly valve, the flow reacts to small positioning steps however there is no proportion flow variation after the further opening of the valve due to the S-shape performance curve. Considering the behaviour of the conventional butterfly valve, its use for flow control purposes is considered inefficient. This drawback of the conventional butterfly valve has been eliminated in tricentric design. The loss coefficient for the tricentric design is less than the conventional butterfly valve and globe valve for the same percentage of valve opening. Similarly, the flow coefficient of tricentric design is better than the conventional butterfly valve and globe valve for the same percentage of valve opening. Therefore, to achieve the same flow rate the differential pressure resulting across the tricentric valve is less than the conventional type i.e., the flow control is achieved with less energy loss resulting in energy conservation. The study reveals that the characteristics of valves established by CFD with conventional experimental results which are near optimum results. The CFD analysis is a substitute for experimentation in certain conditions.

6 Conclusion
The study reveals that the tricentric butterfly valve has the merits over the conventional butterfly valve and globe valve in terms of construction, ease of installation, operation, and also overcoming its limitations. The triple offset metal seat design of tricentric valve provides superior performance and advantages over a broad range of applications. The equal percentages of tricentric valve characteristic provide good results and are very tolerant of over-sizing. It will further offer a more constant gain in control as the load changes. The study reveals that the CFD can be an alternative solution and complement to experimental validations in certain simulated conditions.
The future scope of the research has opened up for experimenting plug, piston type valves for gaseous application with CFD analysis.

Acknowledgement
The authors are grateful to Shri A. K. Agrawal Director, CWPRS, Pune, for giving the guidance and motivation throughout the studies. The authors are also thankful to Shri P M Abdul Rahiman Scientist ‘E’ for his continuous support and guidance during the period of investigations at various stages.

References
[1] Lyons, J.V. Valve Designer's Handbook. Nostrand Reinhold Company, New York, 1983.
[2] Tullis, J.P. Hydraulics of Pipelines - Pumps, Valves, Cavitation and Transients. John Wiley and Sons, New York, 1989.
[3] Fisher Controls International. Control Valve Handbook. Fisher Controls. Marshall Town, 1977.
[4] Zappe, R.W. Valve Selection Handbook. Gulf Publishing Company, London, 1981.
[5] HolgerSiemers. Notes from Valve World. www.valve-world.net, 2007.
[6] Guan Song Xue and Young Chul Park. WCECS 2007. Numerical Analysis of Butterfly Valve-Prediction of Flow Coefficient and Hydrodynamic Torque Coefficient. 24-26 Oct 2007, San Francisco, USA.
[7] Weir Technical Bulletin, Weir Valves and Controls, USA, 2010.
[8] Ogawa, K and Kimura, T. Hydrodynamic Characteristics of a Butterfly Valve — Prediction of Torque Characteristic, ISA Transactions, 1995, 34, 327-333.
[9] Huang, C.D. and Kim, R.H. Three-Dimensional Analysis of Partially Open Butterfly Valves Flows. Transactions of the ASME, 1996, 118, 562-568.
[10] M.-J. Chern, C.-C. Wang. Control of Volumetric Flow-rate of Ball Valve Using V-Port, Journal of Fluids Engineering, 126(3) (2004) 471- 481.
[11] Kirik, M.J. and Driskell, L.R. Flow Manual for Quarter-turn Valves, Rockwell International Co, London, 1986.