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CFD Analysis of a Butterfly Valve to Optimize its Design

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Abstract - Butterfly valves are flow control devices that are often used to control fluid flow in a pipe segment. Fluid flow behaviour research in valves has resulted in a continuing effort to improve valve design. The numerical solution of three-dimensional, stable, incompressible, turbulent k-navier stokes equations predicts flow behaviour and flow coefficient. CFD assists in design optimization by enhancing accuracy and drastically lowering design lead time.

The goal of this study is to look at how different valve designs affect pressure drop, flow coefficient, loss coefficient, and flow behaviour. Based on the baseline simulation results, an ideal design is provided. The projected flow coefficient of the improved design is 31.56 percent higher than the baseline configuration. In the event of an ideal design, the hydrodynamic torque coefficient, which determines the opening and closing of the valve disc, seems to be larger. For the final optimized design, the loss coefficient, which is related to head losses, decreases.

Key Words: Flow control device, Flow coefficient, Hydrodynamic torque coefficient, Butterfly valve, CFD analysis.

INTRODUCTION

The flow properties of butterfly valves of various sizes were investigated to identify the impacts of turbulence models. Some valve manufacturers created valves with linear properties. These valves are 10-100 times more costly than butterfly valves. The authors of this work hoped to obtain the same level of control precision with butterfly valves as with valves with logarithmic flow characteristics. The flow properties of butterfly valves were investigated in order to evaluate the impacts of turbulence models.

The flow rate of heating extraction steam (HEXTR) is the fundamental metric for determining the heat load of a combined heat and power (CHP) plant. A soft-sensing technique based on frequency complementary information fusion is presented to combine the benefits of the turbine's Flügel formula as a static model with the butterfly valve flow characteristics method. According to the actual operational data, the soft sensor's relative static measurement

error is less than 1%, and the dynamic reaction is as rapid as the power load change. The study described here was designed to measure the impacts of butterfly and gate valves installed upstream of water metres with diameters more than 50 mm. According to the ISO 4064-1:2018 standard, several water metres are authorised for a certain flow disturbance sensitivity class. However, this categorization of metres does not account for all sorts of flow perturbations. Two types of valves, butterfly and gate, were evaluated upstream of ten brand-new water metres from six different manufacturers built in four distinct metering technologies for this study.

Buttery valves are frequently used in industrial applications to regulate the internal flow of both compressible and incompressible fluids. A butterfly valve is typically comprised of a metal disc formed around a central shaft that acts as the valve's axis of rotation. Fluid may flow more freely through the valve as the opening angle, of the valve increases from 0o (fully closed) to 90° (totally open). Buttery valves must be sturdy enough to withstand the stresses and forces induced by high Reynolds number flows. Caterizing a valve's performance characteristics, such as pressure drop, hydrodynamic torque, flow coefficient, loss coefficient, and torque coefficient, is essential for fluid system designers to account for system demands in order to appropriately operate the valve and prevent irreparable damage. [1-3].

CFD MODEL

The butterfly valve is a versatile component that may function as both a shutdown and a throttling valve in water systems. Butterfly valves for the water industry are typically available in sizes 78 in. (2,000 mm) and bigger, in accordance with ANSI/AWWA C504-10 (20101, Standard for Rubber-Seated Butterfly Valves) or C516-10 (20101, Standard for Large-Diameter Rubber-Seated Butterfly Valves). Rotating the disc from 0o (closed) to full open regulates the flow (about 90o). A butterfly valve's effective throttling range is 15° to 75° open, however this may vary depending on the application. Lower-angle throttling might cause erosion or cavitation due to high velocities [4-6].

Three different geometries of 48-inch flow regulating valve, Model-I, Model-II and Model-III in fully open condition as shown in Fig. 1, 2 and 3 respectively considered for the present analysis. The design parameters such as diameter of disc, thickness and shaft rod diameter shown in Table 1.

The Model-I has flat surfaces from both sides and is type of asymmetric valve. In the Model-II valve, disc thickness reduced from 50 mm to 30 mm and disc profile is convex from both sides also the shaft rod diameter reduced from 100 mm to 70 mm. The disc shape of Model-III is like cone from one side and flat from one other side. Models wear created by the using ANSYS Workbench [9-10].

TABLE -1: Design Parameters of Butterfly Valve Disc

	Model- I	Model-II	Model-III
Disc Diameter, D (mm)	1200	1200	1200
Thickness, t (mm)	50	30	100(centre) to 30(outer edge)
Shaft rod diameter, d (mm)	100	70	70

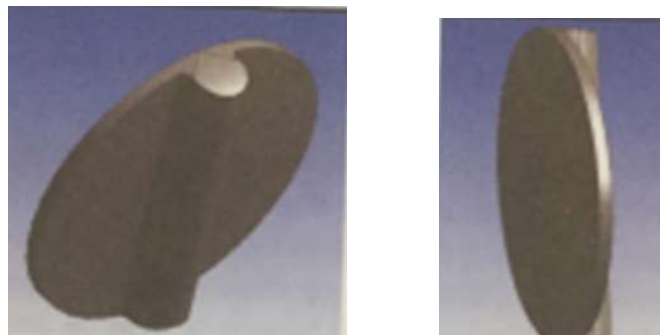


FIGURE 1 Model-I (Baseline Design)

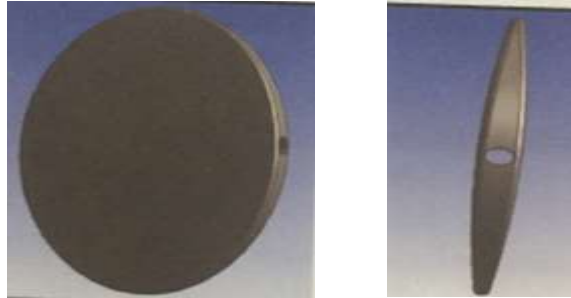


FIGURE 2 Model-II (Optimized Design)

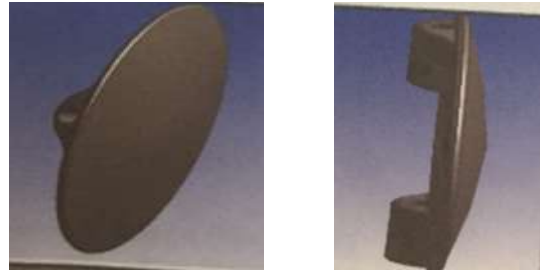


FIGURE 3 Model-III (Final Optimized Design)

ENCLOSURE (PIPE)

In this work, enclosure is used as pipe for butterfly valve that encloses valve disc, the material assigned for the enclosure is fluid, and valve disc material is taken as solid. Shape of the enclosure is taken as cylindrical. The diameter of cylinder is taken as 1200 mm and it is extended towards the upstream side up to 2D that is up to 2400 mm and 7200 mm on opposite direction that means in downstream side up to 6D. Fig. 4 shows the assembly of enclosure (Pipe) and the valve disc.



FIGURE 4 Assembly of Enclosure (Pipe) and the valve disc

GEOMETRY MESHING

ANSYS Fluent is used to generate an unstructured tetrahedral element with high density around the valve seat area and prisms at the near-wall to capture the wall Y^+ . To increase the flow field, the flow domain is expanded to 2D on the upstream side and 6D on the downstream side, as illustrated in Fig.

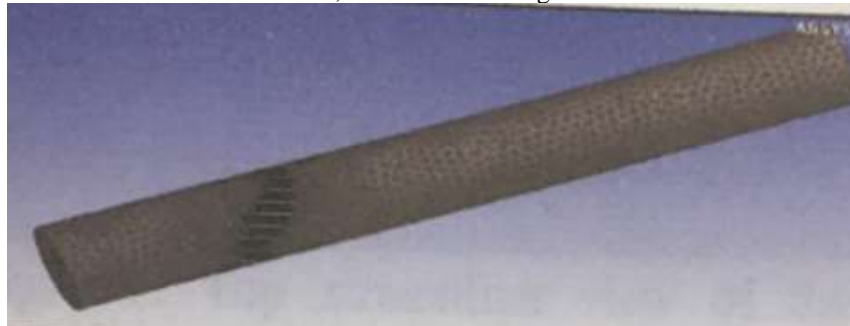


FIGURE 5 Meshed assembly of valve disc and pipe



FIGURE 6. Meshing view of MODEL-I disc



FIGURE 7 Meshing view of MODEL-II disc

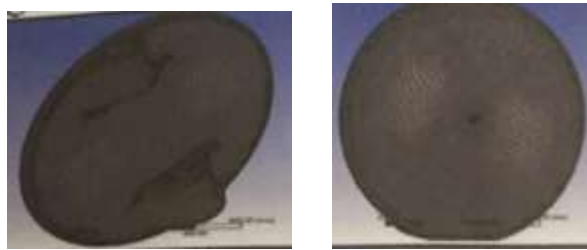


FIGURE 8 Meshing view of MODEL-III disc

BOUNDARY CONDITIONS

Boundaries in three dimensions are surfaces that fully encircle and define an area. Each boundary has its own set of features that may be customised, such as meshing surface size or how it should behave in relation to other surfaces. The following boundary types were chosen: wall, internal interface, velocity intake, and flow exit.

Boundary conditions:

- Inlet – Velocity @ 4.6 m/s
- Outlet – Atmospheric pressure @ 1 atm
- Turbulent Intensity- 10%
- Hydraulic diameter – 1.2 m
- Wall – No slip, smooth and adiabatic

Fluid Properties:

- Fluid Medium – Water
- Operating conditions – 1 atm, 15°C
- Density of water – 998.2 kg/m³
- Viscosity of water – 0.001003 kg/ms

VISUALIZATION OF THE RESULTS

Baseline Design (Model-I)

This type of profile creates variation of static pressure on both the sides and hence increases the pressure drop across the valve. The effect of stem is seen to increase the pressure. Fig.9 shows the total pressure variation in the center plane of the butterfly valve. Stagnation/recirculation regions are seen in velocity magnitude contour in Fig.10 on the downstream of the valve near the stem region. Path lines shown in Fig.11 show the flow obstruction of flow stagnation due to the presence of stem. It is clear that reducing the stem thickness will help in design optimization in terms of valve weight and cost.

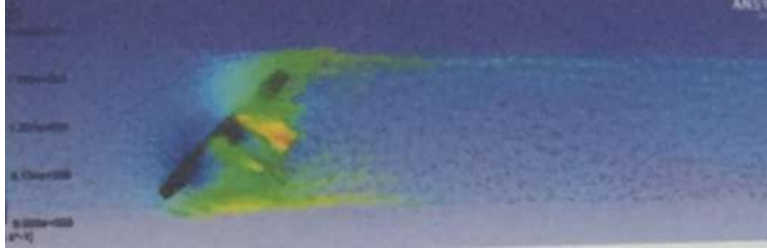


FIGURE 9 Top View of absolute pressure across the Butterfly valve for the 45° Open case of the MODEL-I (Baseline Design)

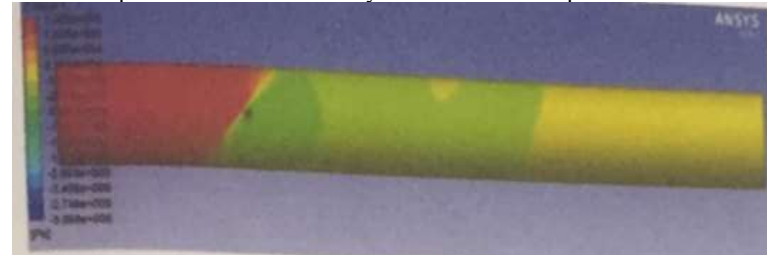


FIGURE 10 Top View of velocity vectors across the valve disc of the MODEL-I for the 45° Open case

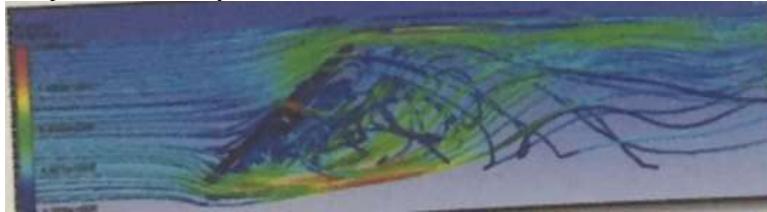


FIGURE 11 Top streamlined view of swirling vortex flow features and the velocity on the surface of 45° Open Butterfly Valve disc of MODEL-I

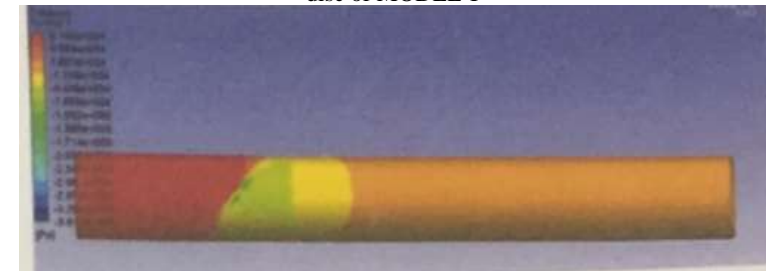


FIGURE 12 Top View of absolute pressure across the Butterfly valve for the 45° Open case of the MODEL-II (Optimized Design)



FIGURE 13 Top View of velocity vectors across the valve disc of the MODEL-II for the 45° Open case



FIGURE 14 Top streamlined view of swirling vortex flow features and the velocity on the surface of 45° Open Butterfly Valve disc of MODEL-II

Optimized Design (Model-II)

Based on the baseline design simulation results, suggested optimized design provides convex profile on both sides. The stem providing more resistance in baseline design in modified and placed at the top of the valve. Smooth curvature is provided on both surfaces of the valve. The optimized design provides better flow behavior and reduced pressure drop across the valve [7-8]. Fig.12 shows the total pressure variation in the center plane of the butterfly valve. Stagnation/recirculation region is removed from the downstream as is seen in velocity magnitude contour in Fig.13. Path lines shown in Fig.14 show the smooth flow near the valve region.

Final Optimized Design

Based on the optimized design simulation results, suggested final optimized design provides cone profile from one side and flat from another side. The final optimized design (Model III) provides better flow behavior and reduced pressure drop across the valve. Fig.15 shows the total pressure variation in centre plane of the butterfly valve. Stagnation/recirculation region is removed from the downstream as is seen in velocity magnitude contour in Fig.16. Path lines shown in Fig.17 show the smooth flow near the valve region.

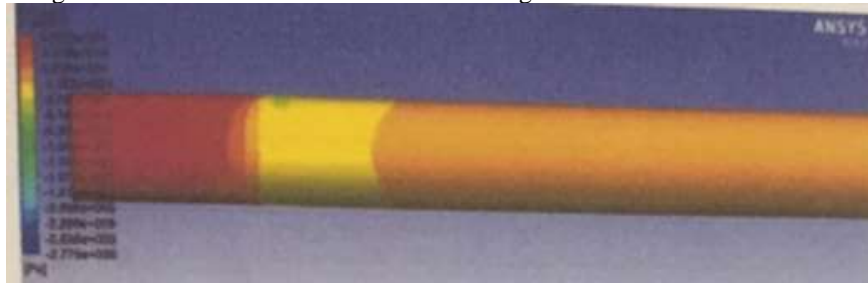


FIGURE 15 Top View of absolute pressure across the Butterfly valve for the 45° Open case of the MODEL-III (Final Optimized Design)

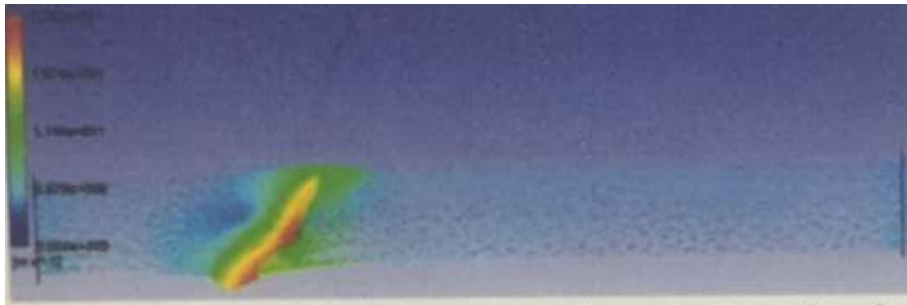


FIGURE 16 Top View of velocity vectors across the valve disc of the MODEL-III for the 45° Open case

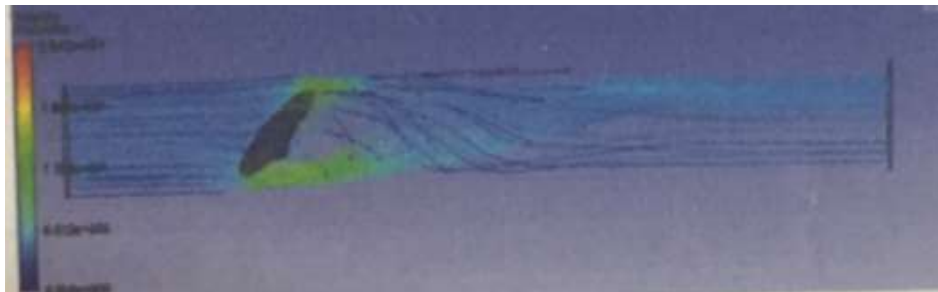


FIGURE 17 Top streamlined view of swirling vortex flow features and the velocity on the surface of 45° Open Butterfly Valve disc of MODEL-III

COMPARISON OF RESULTS

The pressure drop, ΔP_0 , as seen in Fig.18 and Table 2, shows that there is large pressure drop in the Model-I as compared to the Model-II and Model-III. It is seen that as the valve opening angle increases from 10 degree to 90

degree, pressure drop goes on decreasing. Pressure drop is maximum at 10 degree opening and minimum at 90 degree opening. As the shape, changes are made in baseline design of valve disc the pressure drop decrease to great extent.

The flow coefficient, C_v as seen in Fig 19 and Table 3, demonstrates the results for all valve angle opening. The flow coefficient is used to relate to the pressure loss of a valve to the discharge of the at a giving valve opening angle. From Fig. 19, it is seen that the flow coefficient for Model-III (Final Optimized Model) is maximum and it is maximum at 90 degree valve opening angle. Flow coefficient of Model-III is increased by 31.56% compared with baseline design Model-I) of valve disc for a 45-degree valve opening angle. The flow coefficient of models goes on increasing as valve opening angle increases.

The torque coefficient, C_t as seen in Fig. 20 and Table 4, shows that the values of the torque coefficient for butterfly valve goes on increasing up to 80 degree and suddenly decreases to zero at 90-degree valve opening angle. Torque coefficient values are maximum for Model III and II. The torque coefficient, C_t is also near to zero at 10-degree valve opening angle.

The loss coefficient, K_o as seen in Fig. 21 and Table 5, shows an overall agreement in the pattern of the results for all valve angle openings. The loss coefficient, K_o , is minimum for final optimized model (Model-III) from 10-degree valve opening to 90-degree valve opening angle. It goes on decreasing as the valve opening angle goes on increasing. Its value is maximum for baseline design (Model-I).

TABLE2. Comparison of Pressure drop results between the MODEL-I, II, III

Angle (degree)	Pressure loss , Delta Ptheta * 10 (Pa)		
	Model-I	Model-II	Model-III
10	235.576	207.82	174.29
20	83.61	78.15	61.39
30	36.623	21.543	14.39
40	16.535	6.494	6.814
45	10.233	6.321	4.734
50	5.857	3.005	3.361
60	2.562	1.787	1.7358
70	1.62	1.3907	1.3109
80	0.7422	0.5369	0.5346
90	0.54816	0.1788	0.17879

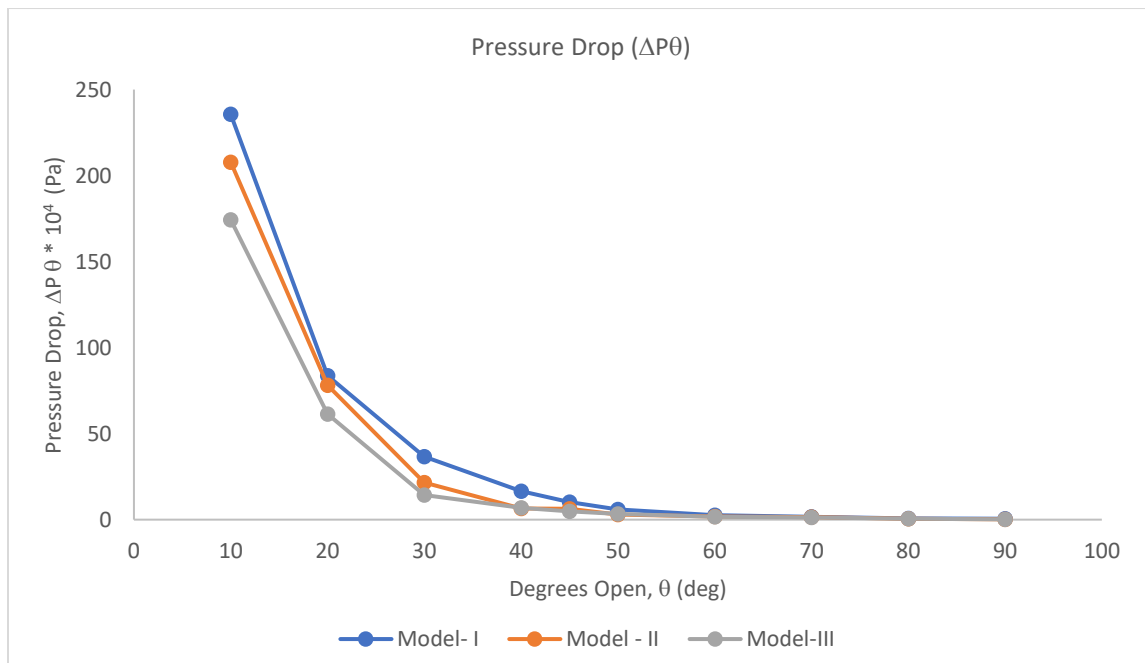


FIGURE 18: Comparison of Plot of Pressure drop results between the three MODELS- I, II, III

TABLE3. Comparison of Flow Coefficient results between the MODELS-I,II,III

Angle (degree)	Flow Coefficient, Cv(kgs ⁻¹ Pa ^{-1/2})		
	Model-I	Model-II	Model-III
10	0.594049	0.756548	0.8305
20	3.00737	4.437634	4.430335
30	6.790343	9.172022	10.86861
40	10.54053	16.24881	16.62385
45	13.79962	16.24881	20.15091
50	19.05089	24.37831	24.89348
60	30.06598	33.5462	35.13141
70	37.9072	40.12761	40.46342
80	57.22514	67.05603	67.51949
90	67.72698	117.3657	118.4531

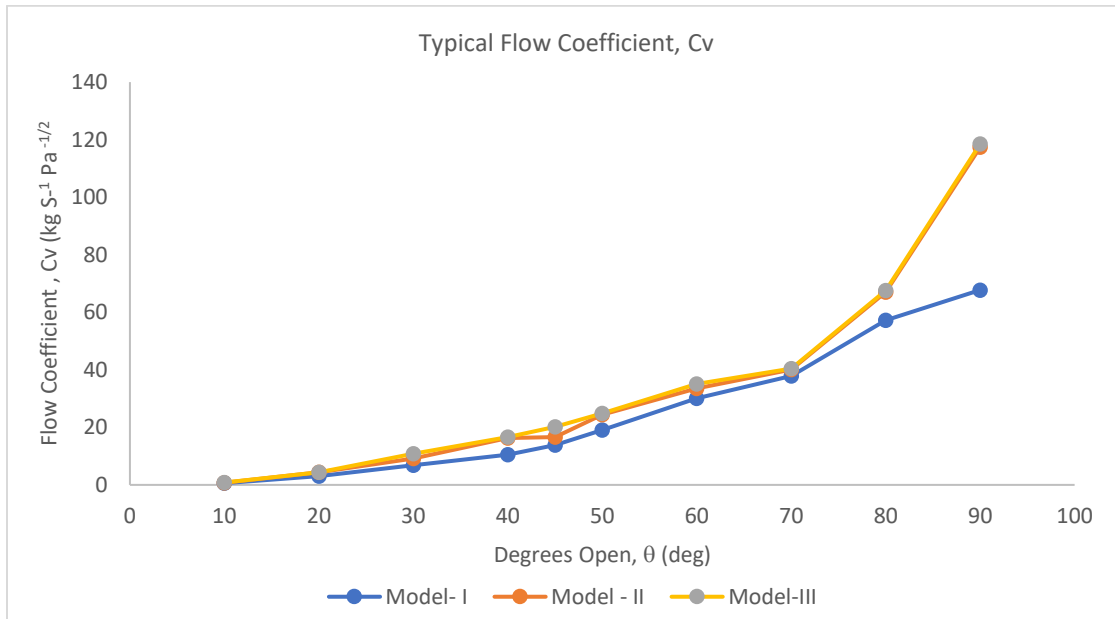


FIGURE 19. Comparison Plot of Flow Coefficient results between the MODELS - I, II, III

TABLE. 4 Comparison of Torque coefficient results between the MODELS I, II and III

Angle (degree)	Typical Torque coefficient, Ct		
	Model-I	Model-II	Model-III
10	0.010822	0.010057	0.005414
20	0.018249	0.019613	0.019709
30	0.022858	0.050722	0.051481
40	0.037988	0.096259	0.057745
45	0.044951	0.075302	0.070643
50	0.082407	0.131524	0.121266
60	0.122001	0.215817	0.240278
70	0.112789	0.206088	0.220152
80	0.096319	0.294605	0.269937
90	-0.12379	-0.00167	0.269937

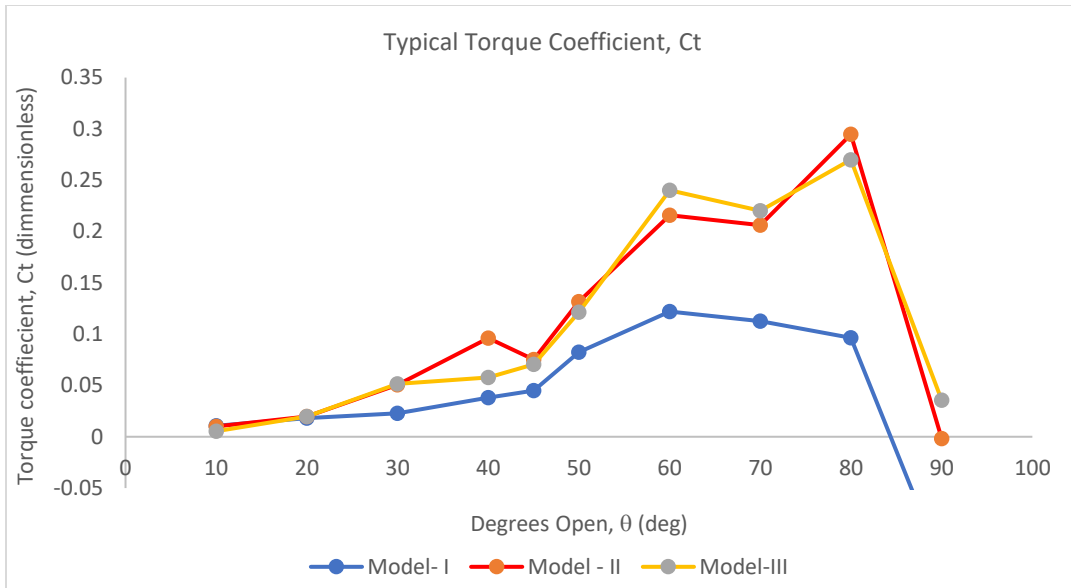


FIGURE 20. Comparison Plot of Torque Coefficient results between the models I,II and III

TABLE. 5 Comparison of Loss Coefficient results between the MODELS I, II and III

Angle (degree)	Loss Coefficient, K_{θ}		
	Model-I	Model-II	Model-III
10	222.6616	196.4272	164.7353
20	79.02647	73.86578	58.02457
30	34.61531	20.362	13.60113
40	15.62854	6.137996	6.440454
45	9.672023	5.97448	4.47448
50	5.535917	2.840265	3.176749
60	2.42155	1.689036	1.640643
70	1.531191	1.314461	1.239036
80	0.701512	0.507467	0.505293
90	0.51811	0.168998	0.168989

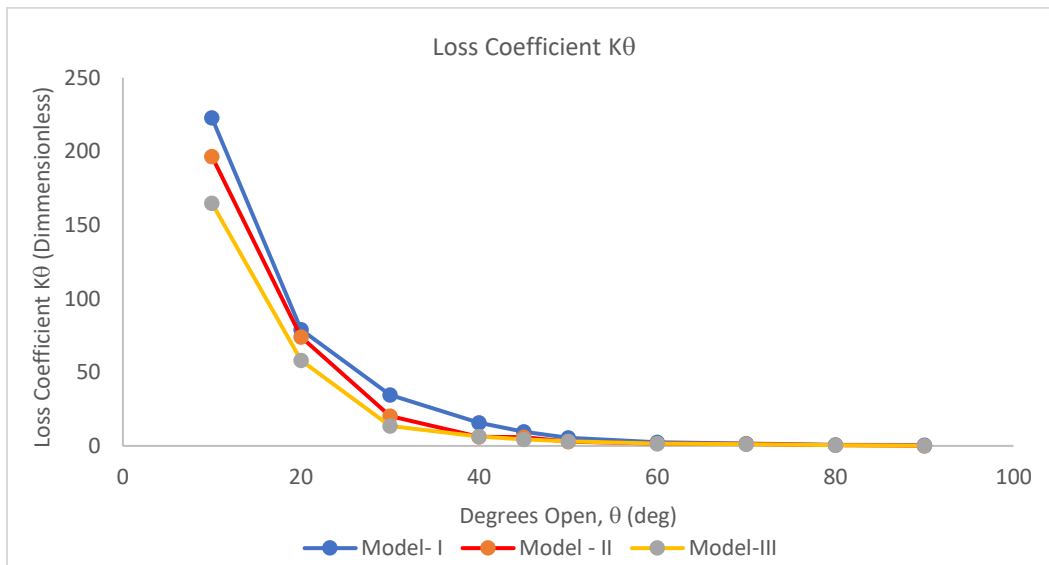


FIGURE 21. Comparison Plot of Loss Coefficient results between the MODELS I,II and III

CONCLUSIONS

The flow behaviour across the flow controlling butterfly valve is predicted via numerical modelling. For the simulation, three distinct designs (Model-I, Model-II, and Model-III) are explored. The following observations were made:

- Pressure, velocity, and streamline charts are used to forecast flow behaviour.
- Due to the existence of the stem, a considerable recirculation/stagnation zone is formed in the downstream side of the valve in Model-I. Flow coefficient increases by 31.56 percent in Model-III when compared to Model-I at 45 degree opening.
- The hydrodynamic torque coefficient appears to be increased in the Model-III design by reworking the disc. It controls the valve's opening and shutting.
- In the final optimised design, the loss coefficient is likewise lowered (Model-III).
- The current improved design (Model-III) improves the flow field and flow coefficient while lowering production costs.
- More study on other valve openings, different turbulence models, and experimental data validation for the optimal design will add value to this work.

FINAL REMARKS

- Computational fluid dynamics remains an outstanding tool for modelling real-world situations. CFD, on the other hand, may be utilised to provide insight into the visualisation of complicated flows and flow issues.
- CFD was used to describe the overall behaviour of fluid flow for an incompressible fluid around a butterfly valve at angles ranging from 10-90 degrees in this work. CFD was able to accurately estimate all of the usual performance flow parameters of a butterfly valve for mid-opening valve angles (30-60 degrees). It is best to avoid using expected outcomes from simulated lower valve angle scenarios (10-20 degrees). Higher valve angles (70-90 degrees) can yield fairly expected results, but should be utilised with caution. This is especially useful when experimental models are unavailable.

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