

Course Lecturer: Kelvin Lake

Structural & Fluid Analysis ACMA6010

Designing a Butterfly Valve for A
Fluid Flow Assessment

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Introduction

In this report a detailed description of what Reynolds number is, its importance and an estimated Reynolds number calculation based on an assembly which contains a butterfly valve that is to be inserted into a pipeline that forms the outlet at the base of a 5m high storage tank that contains petroleum at atmospheric pressure will be shown. This will follow with boundary flow, its influence around a butterfly valve and also how turbulence effects this in relation to rivets. For the design of the butterfly valve the material selected will be Glass reinforced plastic (GRP) and the history, industry codes and standards will be discussed. To evaluate and select the most appropriate computational fluid dynamic method a number of methods will be highlighted. Finally, an experiment and simulation will be carried out to obtain data and discuss findings to present a conclusion.

Task One

Reynolds number and Its importance:

Reynolds number, also known as Re is a value that is dimensionless which determines a pattern within a fluid's behaviour. The number is used to distinguish whether the flow of a liquid is laminar or turbulent. (Rehm, 2019)

Laminar flow is a type of fluid flow which the fluid travels smoothly or in a regular path of particles of the fluid. Sometimes called streamline flow where the properties such as Velocity and pressure remain constant. Laminar flow over a horizontal surface can be thought of as consisting of thin layers all parallel to each other. The fluid in contact with the horizontal surface is stationary, but all the other layers slide over each other. (Britannica, 2019) Also, fluids with a high viscosity will flow more slowly and therefore the internal roughness of the pipe will have no effect on the frictional resistance.

Turbulent flow is a type of fluid flow which the fluid undergoes irregular fluctuations, or mixing, in contrast to laminar flow, in which the fluid moves in smooth paths or layers. In turbulent flow the speed of the fluid at a point is continuously undergoing changes in both magnitude and direction. (Britannica, 2019)

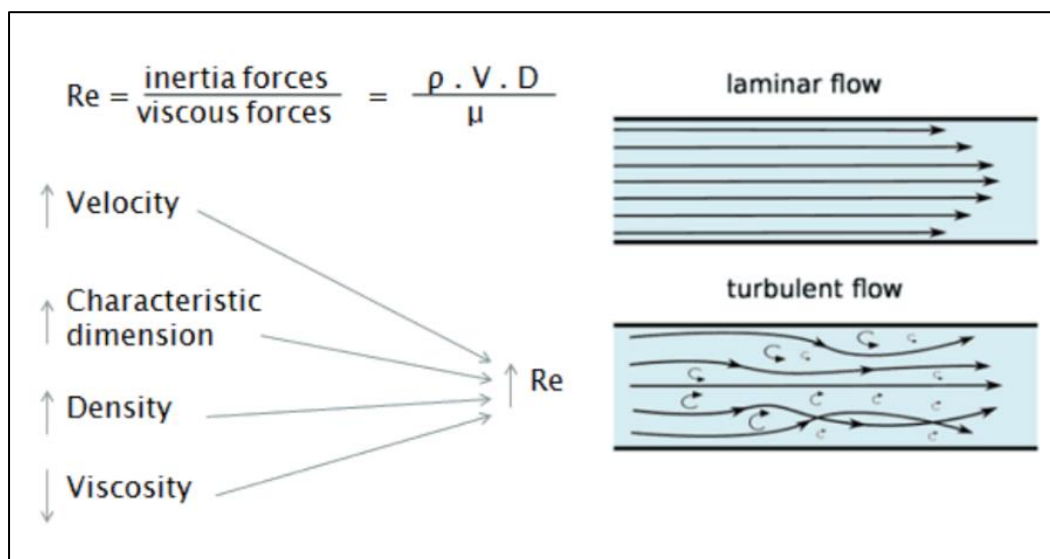
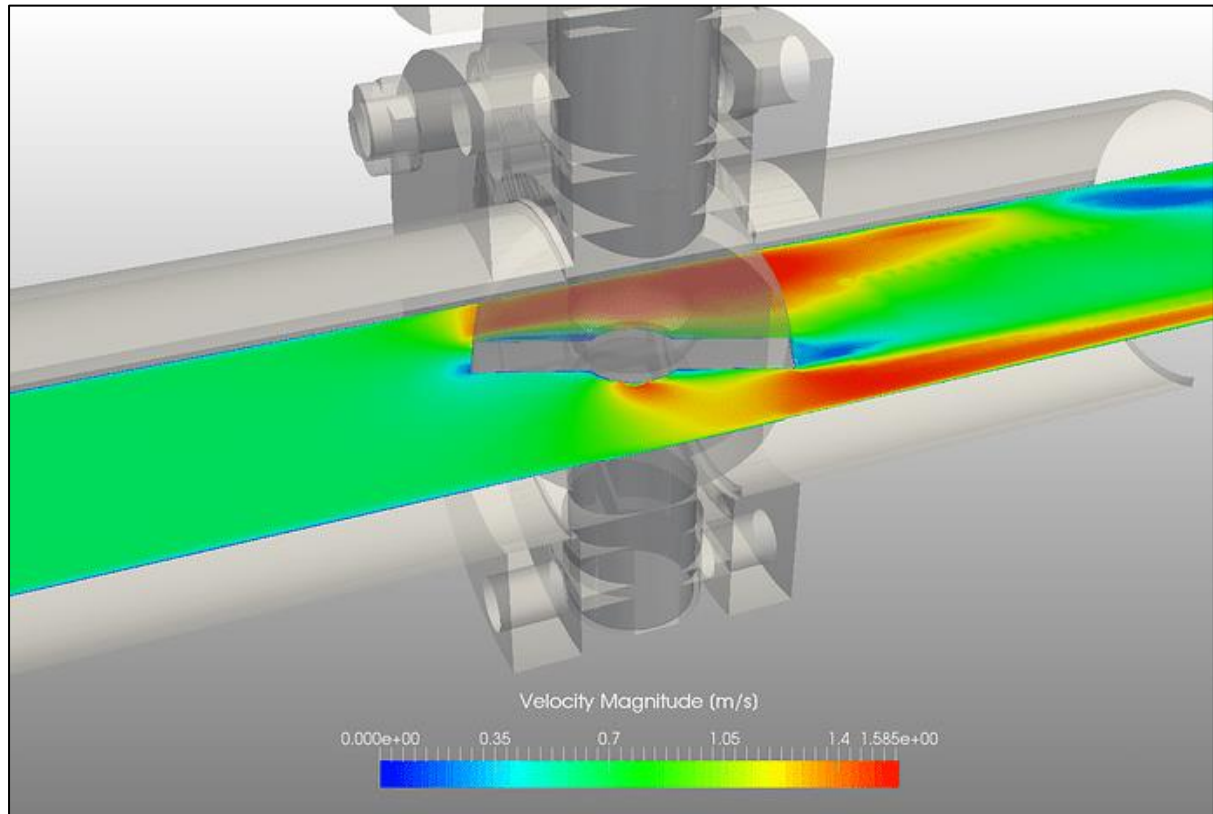


Figure 1: (Rodriguez, 2021)

A butterfly valve is a type of flow control device, used to control and regulate fluid flowing through a pipeline. The butterfly valve is very similar in the way a ball valve operates. A disc is positioned in the centre of the pipe and typically has a rod through it connected to an actuator which is located on the outside of the valve.

The actuator turns the disc to control the flow. Regardless of valve position, the disc on the butterfly valve is always positioned within the flow, therefore a pressure drop is always presented across the valve. A butterfly valve is a type of valve sometimes called a quarter-turn valve. Because when fully opening the valve, the disc is rotated a quarter turn so that it allows the fluid to go through the valve in an unrestricted passage. The important characterises to understand are the flow coefficient and the loss coefficient when it comes to valve performance. (Toro, 2012)



(SCALE, 2020)

Reynolds numbers Calculation:

Mathematically the Reynolds number for flow can be defined as follows:

$$Re = \frac{\rho V D}{\mu}$$

Where Reynolds number from :

P is the density of the fluid (kg/m³)

V is the velocity of the fluid (m/s)

D is the pipe diameter (m)

u is the dynamic viscosity of the fluid (kg/m.s)

Assembly which contains a butterfly valve that is to be inserted into a pipeline that forms the outlet at the base of a 5m high storage tank that contains petroleum at atmospheric pressure:

P is the density of the fluid: 750 (kg/m³)

V is the velocity of the fluid: 9.9 (m/s)

D is the pipe diameter: 0.194 (m)

u is the dynamic viscosity of the fluid 0.00029 (kg/m.s)

$$Re = \frac{750 \times 9.9 \times 0.194}{0.00029}$$

Estimated Reynolds Number = 4967068 (4967x10³)

For laminar flow $Re < 2000$ and for turbulent flow $Re > 4000$. Flow characteristics are unpredictable if the valve is between these two values.

Please see below details as to the calculation for the dynamic viscosity:

$$\frac{P_1}{\rho g} + \frac{C_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{C_2^2}{2g} + Z_2 + h_F$$

$$\frac{C_2^2}{2 \times 9.81} + 0$$

$$C_2 = \sqrt{5 \times 2 \times 9.81}$$

= 9.9 m/s

Task Two

Boundary flow and its influence around the butterfly valve:

Boundaries are surfaces that completely surround and define a region. Each boundary has its own properties and can be given configurations that are custom, an example of this would be meshing a surface size. This can also show how it should behave relative to other surfaces. The main boundary type chosen to discuss is the Interface between a fluid and a rigid surface. At such a surface, the tangential component of the velocity of the fluid is to be the same as the tangential component of the velocity of the surface, and similarly the normal component of the velocity of the fluid be the same as the normal component of the velocity of the surface.

The boundary condition known as the “no slip” has been found to be successful in describing most practical situations. It was a subject in the eighteenth and nineteenth centuries and was finally accepted because predictions based on assuming it were found to be consistent with observations of macroscopic quantities such as the flow rate through a circular capillary under a given pressure drop. (Subramanian, 2007)

Turbulence and its effects in relation to rivets:

Turbulence occurs not only in pipes but also within the boundary layers around solid obstacles (Rivets) when the rate of shear within the boundary layer becomes large enough. The turbulence in the boundary layer can reduce the drag force on obstacles. In the case of a spherical obstacle, the point at which the boundary layer separates from the rear surface of the sphere shifts backward when the boundary layer becomes turbulent, this is away from the equator “Q” in Figure 2 and toward “P”, therefore the eddies attached to the sphere become smaller. It is turbulence in the boundary layer that is responsible for the dramatic drop in the drag coefficient for both spheres and cylinders. (Britannica, 2019)

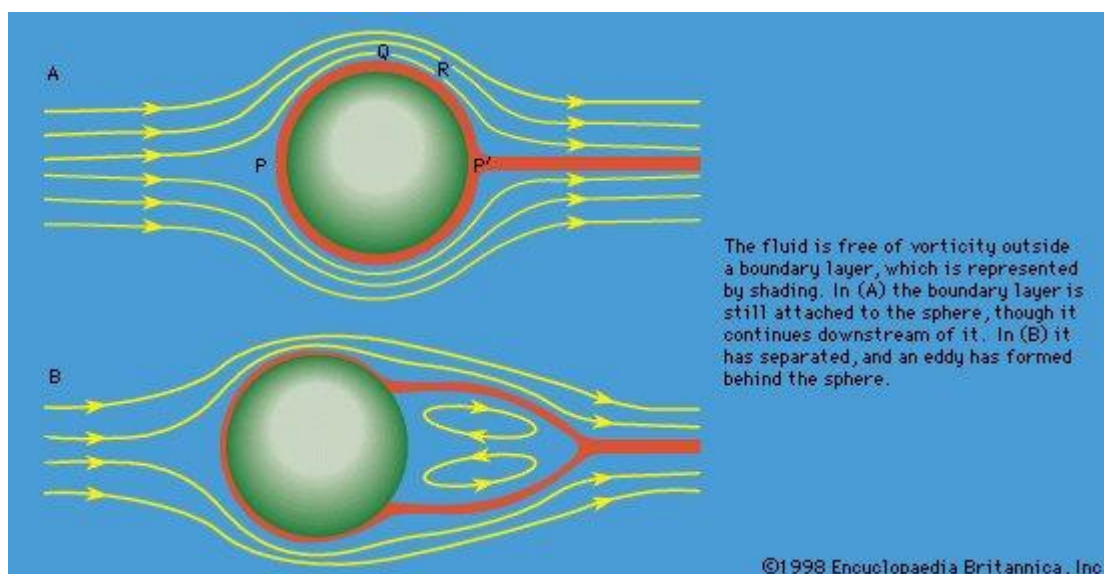


Figure 2 (Britannica, 2019)

A butterfly valve's design is important to understand and is commonly characterised by its own performance factors. How a butterfly valve will perform, while in operation at different opening angles and under different types of flow, is critical information for individuals planning and installing piping systems involving the valve. Performance factors common to a butterfly valve include the following: pressure drop, hydrodynamic torque, flow coefficient, loss coefficient, and torque coefficient.

These valves can normally be obtained experimentally, its sometimes not feasible or possible to calculate the performance of butterfly valves. There are other methods where the butterfly valve performance can be obtained and accessed is by using Computational Fluid Dynamics (CFD) software which simulates the physics of fluid flow in a pipe system around a butterfly valve. (Actucation, 2021)

When it comes to comparing butterfly valves and gate valves, butterfly valves are considered to be cheaper as there is less material, and less civils works to be carried out when manufacturing. They are also considered easier to operate against unbalanced water pressures. Therefore, butterfly valves are most commonly used in industry. There are also various materials to be used when it comes to the seat of the butterfly valve which are usually made from natural or synthetic rubber.

Butterfly valves should normally be mounted with the spindle horizontal since this allows debris in the pipe invert to be swept clear as the valve is closed. Where the spindle is vertical solids can lodge under the disc at the spindle and cause damage to the seal. Disc position indicators are useful and strong disc stops integral with the body should be specified, so this gives certainty to the person when closing the valve.

Typically butterfly valves have been made to very large diameters when operating under very high pressures and water velocities. Many of these valves have proven successful in industry but when use to controlling the flow the maximum velocity should be limited to 5 m/s. Use of such valves for isolation of air valves allows maintenance to be carried out on the air valve but since replacement of air valves is likely to be cheaper than in situ, flanged valves are the preferred option. (Toro, 2012)

Task Three

What is Glass fibre-reinforced plastic (GRP)?

Glass fibre-reinforced plastic, also shortened to GRP, is a fibre-plastic composite. It consists of a plastic, for example based on polyester resin or epoxy resin, and glass fibres. Glass fibre in combination with a plastic matrix offers several advantages. These include high elongation at break, excellent corrosion resistance and very good electrical insulation, which is why the composite is primarily used in the construction. But GRP also performs excellently in water, which is why the composite plastic material is also very popular.

Glass fibre-reinforced plastic can also be individually adapted to any application. Whether particularly impact-resistant, non-slip, antibacterial or in a wide range of colours and decors – GRP is a multi-talent among plastics.

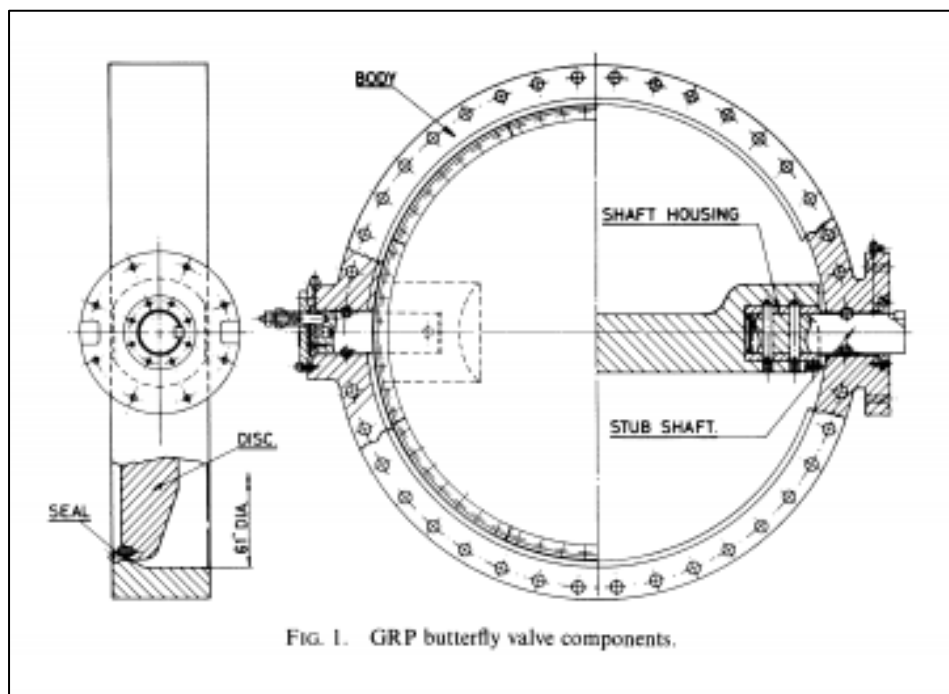


Figure 3 (Walker, 2011)

Materials used to manufacture Butterfly valves:

Carbon steel is an alloy of iron whose main alloying element is carbon. No other alloying elements are added to control the various properties in the material, and it's frequently used to form the body and disc of the valve using a sand-casting process.

Stainless steel as an iron alloy has a minimum chromium content of 10.5% that acts as a self-healer on the surface of the material. That means that in the event that something gets scratched or damaged, the chromium reacts quickly to prevent oxygen from interacting with the iron and forming rust. This alloy has gained popularity over the years and today is one of the most popular materials used to create Butterfly Valves on the market.

Nickel alloys are used in valve components where severe service conditions are encountered. These alloys are particularly useful in harsh corrosive environments, which would attack stainless steels by breaking down their protective oxide layer.

Hastelloy nickel-based alloys are most often used in valve construction. There are several different forms of Hastelloy, with each being tailored by adding specific alloying elements in varying proportions to suit particular service conditions. The main disadvantage of nickel alloys is their weight and cost. Nickel alloys have a high density, and their cost can be many times that of basic stainless steels.

It is also possible to build butterfly valves in an all-plastic design, usually in GRP, with a plastic body and disc, standard rubber lining, and coated-steel stem. The first investigations were made in 1978, by the SW Region of the CEGB, into the feasibility of large GRP butterfly valve manufacture. These investigations resulted in an approach being made to Bovingand Co. Ltd in October 1978 with a view to carrying out a feasibility study into the design of a 60-in diameter valve for Fawley Power Station. (Walker, 2011)

History:

The butterfly valve concept is pretty common. The choke in a carburettor, for example, is a butterfly valve. Its application for industrial piping, though, began only in the 1930s. For years one of the main applications of butterfly valves was in oil field use. Eventually, their use spread to a number of industries, but as the various types of butterfly valves appeared the attempts that were made at standardisation were not very successful. For a long time, the butterfly valve was one of the least standardised of all valves in the fluid-processing industries.

There was a standard for flanged waterworks valves, and then later a standard for rubber-lined lug and wafer valves. Finally, in 1982, the high-performance valve joined the world of standardisation. It is still possible to buy valves that are not standard end to end to replace valves built prior. (Actucation, 2021)

Industry Codes and Standards:

- API 609 - Butterfly Valves: Double Flanged, Lug and Wafer Type
- BS 5155 - Specification for butterfly valves
- MSS SP 67 - Butterfly Valves

See below from BS 5155 British standard table 8 for butterfly valve components, Material, and grades:

Table 8 — Basic materials

1	2	3	4
Component	Material	BS reference	Grade or designation
Body	Cast iron	1452	180 min. ^a
Body with integral seat	Austenitic cast iron	3468	190 N/mm ² min. tensile strength
Disk	Spheroidal graphite iron	2789	All grades
Handwheel	Carbon steel	1501-151 1503-221 1504-161	360 min. 410 min. 430 min.
Disk with integral seat	Stainless steel	1501-3 1503 1504, 3100 1504	304S15 or 316S16 304S31 or 316S31 304C15 or 316C16 420C29
Rings fitted to body or disk for sealing, seating, or retaining purposes	Gunmetal	1400	LG2, LG4
	Aluminum bronze	1400	AB2
	Rings of deposited metal or resilient material ^b		
Shaft	Carbon steel	970-1	080M40, 212M36
	Stainless steel	970-4	304S15, 316S16, 320S17, 431S29
	Aluminum bronze	2872 or 2874	CA104, CA106
	Nickel copper alloy	3076	NA13
Shaft bearings seals (when fitted)	No requirement in this standard		
Internal fastenings	Carbon steel	Specific grades are outside the scope of this standard	
	Stainless steel		
	Phosphor bronze	2870, 2873	PB 102
	Aluminum bronze	2872, 2874, 2875	CA104, CA106
	Nickel copper alloy	3076	NA13

(BS Standard 5155; 1984)

Task Four

Computational fluid dynamics (CFD): models attempt to simulate the interaction of liquids and gases where the surfaces are defined by boundary conditions. They also track the flow of solids through a system. These models employ the principles of the Navier-Stokes's equations. Simulations are then conducted by solving the equations iteratively as either a steady-state or transient condition.

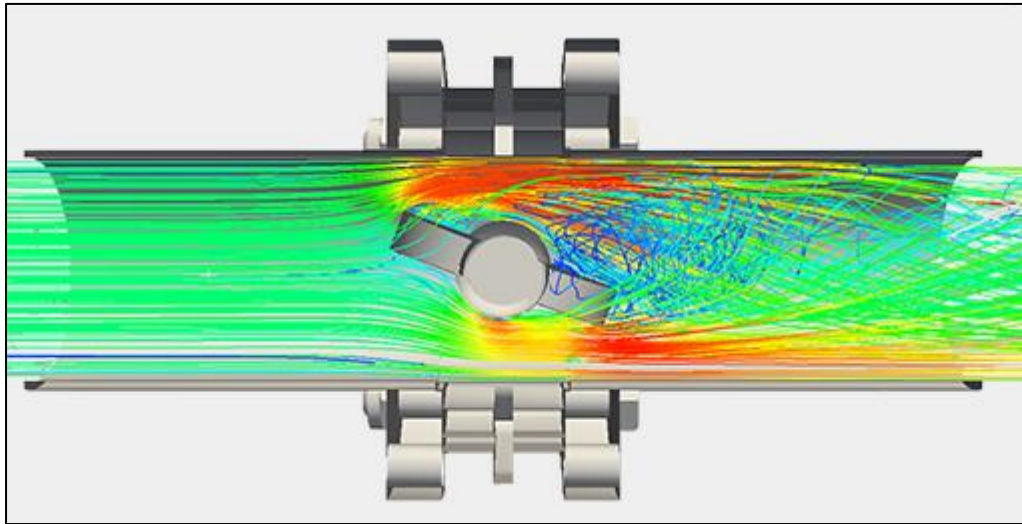


Figure 4 (SCALE, 2020)

Finite volume method (FVM): is based on an unstructured mesh. Therefore, it is suitable for irregular and complex geometries. FVM is based on the integral form of the conservation laws, rather than their differential form. This leads to more accuracy/stability, especially for sharp gradients. The dynamics of flow can be described by conservation of mass, momentum, and energy. These conservation laws can be written as a system of PDEs. Alternatively, conservation laws can be expressed by integral equations (Reynold's transport theorem).

Finite element method (FEM): it is a technique that makes use of computers to predict the behaviour of varied types of physical systems such as deformation of solids, heat conduction, and fluid flow. FEA software, or FEM software, is a very popular tool used by engineers and physicists because it allows the application of physical laws to real-life scenarios with precision and practicality.

The finite element method is a mathematical procedure used to calculate approximate solutions to differential equations. The goal of this procedure is to transform the differential equations into a set of linear equations, which can then be solved by the computer in a routine manner. Differential equations are very important and present in many engineering problems because they represent the language in which physical laws are expressed. They connect changes in the internal variables of an object, such as displacement, temperature or

pressure, and their relation with the object's geometry, physical properties, and external influences acting on it. (Koutromanos, 2017)

The Finite difference method (FDM):

is an approximate method for solving partial differential equations. It has been used to solve a wide range of problems. These include linear and non-linear, time independent and dependent problems. This method can be applied to problems with different boundary shapes, different kinds of boundary conditions, and for a region containing a number of different materials. The application of FDM is not difficult as it involves only simple arithmetic in the derivation of the equations and in writing the programs. During 1950–1970 FDM was the most important numerical method used to solve practical problems, With the development of high-speed computers having large scale storage capability many numerical solution techniques appeared for solving partial differential equations. However, due to the ease of application of the finite difference method it is still a valuable means of solving these problems.

Finite-Element Method (FEM): Advantages and Disadvantages

The finite element method's success in multi-physics analysis is that it is a very general method. Solving the resulting equation systems are the same or very similar to well-known and efficient methods used for structural and electromagnetics analysis. Another reason for the method's success is that it makes it easy to "increase the order of the elements" so that the physics fields can be approximated very accurately. This typically corresponds to locally approximating the physics fields with polynomials of "higher order," such as second- and third-degree polynomials, or higher. This technique is often critical, for example, in the case of accurate stress analysis. (Oñate, 2009)

Finite-Difference Method (FDM): Advantages and Disadvantages

The finite-difference method is defined dimension per dimension as this makes it easy to increase the "element order" to get higher-order accuracy. If you can fit the simulation in a rectangular or box-shaped geometry using a regular grid, efficient implementations are much easier than for finite-element and finite-volume methods. (Mazumder, 2015)

Finite Volume Method (FVM): Advantages and Disadvantages

The advantages of this method over FDM are it doesn't require the use of numerical grid internally is completely avoided, but as with FDM, the results approximate solutions are discrete. This variable is typically placed at cell centres rather than nodal points. This is not always the case however, as there are also face centred finite volume methods. In the case where the values of field variables at non storage locations are obtained using interpolation. The accuracy of the FVM, can be increased by refining the mesh around a corner, similar to the FEM. However, unlike the FEM, the functions to estimate the solution is not easily made for higher order. Therefore, this is a disadvantage of the FVM versus the FEM. (F. Moukalled, 2015)

Task Five

Quality and prechecks prior to experiment:

Butterfly valves are pressure vessels that must meet stringent requirements to bear medium pressure without leakage. Its body, cover, and other critical components must be free from cracks, loose pores, slag, and other defects that affect the strength. There are several valve tests that can be completed throughout the production process. It's important to conduct valve testing at each step, from design, to manufacture, installation, operation, and maintenance. However, the most important valve test is quality test. Quality assurance specialists perform multiple close appearance inspections and valve-specific performance tests to expose any defects and adjust accordingly. Only after all the tests are qualified can the product be put into use. Butterfly valves requires strength test. To test a butterfly valve's sealing performance, the test medium should be introduced from the medium inflow end. Make sure the butterfly plate is opened, the other end closed, and inject the test medium at the pressure specified by your testing requirements. After ensuring there is no leakage at the stuffing and other sealed parts, close the butterfly plate. Open the other end, if there is no leakage at the butterfly plate's sealing, it is considered qualified. The butterfly valve that is used for flow regulation can skip the sealing performance test.

Simulation and conclusion of results:

The total valve opening is from 0 degree (closed condition) to 90 degree (fully open condition). Following are the conditions and the performance in terms of flow characteristics and pressure drop for butterfly valve design:

1. 30 degree open- 75 kg/s (flow rate)
2. 45 degree open-100kg/s
3. 60 degree open-150kg/s
4. 75 degree open -185kg/s

To do CFD simulation at 30 degree opening, valve geometry is rotated by 30 degree. simulation Hub is available as integrated app within on shape. The application is added using "Add Application" option.

A new simulation Hub tab is added within on shape environment. Once the simulation name is given, the valve geometry with 30-degree opening is transferred to simulation Hub. Further process of extracting fluid volume, setting up boundary conditions and simulation run is followed in simulation Hub tab. For each opening angle, the simulation process took about 4 minutes of time. Same procedure is followed for other openings. Doing the same with all the four angles with design and simulation for butterfly valve.

Conclusion

The study to compare experimental and simulated CFD performance factors of a butterfly valve for various valve openings and flow conditions were completed in order to determine the validity of using CFD and to predict butterfly valve performance factors. The results typically found that for a mid-open butterfly valve in the positions (30-60 degrees), CFD was able to appropriately predict common performance factors. Also, for the higher valve angles at (70-90 degrees) the results gave mixed results. Where, for the lower valve angle cases at (10-20 degrees), CFD simulations failed to predict the same valves. As to the material selection being Glass reinforced plastic (GRP), it shows that there have been many attempts to standardise the material selection and now at present it normalises its use in industry. There are many companies providing GRP solutions.

References

- Actuation, V., 2021. *A COMPLETE GUIDE TO BUTTERFLY VALVES*. [Online]
Available at: <https://www.actuation.co.uk/guide-butterfly-valves>
[Accessed July 2021].
- Britannica, T. E. o. E., 2019. Laminar Flow.
- BS Standard 5155:, B. S., 1984. *Specification For Butterfly Vavles*, s.l.: British Stanards Online.
- F. Moukalled, M. D. L. M., 2015. *The Finite Volume Method in Computational Fluid Dynamics: An Advanced Introduction with OpenFOAM® and Matlab*. 1st ed. s.l.:s.n.
- Koutromanos, I., 2017. *Fundamentals of Finite Element Analysis: Linear Finite Element Analysis*. 1st ed. s.l.:John Wiley & Sons.
- Mazumder, S., 2015. *Numerical Methods for Partial Differential Equations: Finite Difference and Finite Volume Methods*. 1st ed. s.l.:s.n.
- Oñate, E., 2009. *Structural Analysis with the Finite Element Method. Linear Statics*. Volume 1 : The Basis and Solids ed. s.l.:s.n.
- Prabhakara, S., 2004. The No-Slip Boundary Condition in Fluid Mechanics. *Solution of the Sticky Problem*.
- Rehm, B., 2019. *Marine Propellers and Propulsion (Fourth Edition)*. 4th ed. s.l.:Science Direct.
- Rodriguez, M. E., 2021. *THEORY BITES: REYNOLDS NUMBER*. [Online]
Available at: <https://empoweringpumps.com/theory-bites-reynolds-number-criterion/>
[Accessed July 2021].
- SCALE, S., 2020. *Software for Valve simulation*. [Online]
Available at: <https://www.simscale.com/valves-simulation/>
[Accessed July 2021].
- STEIN, J., 2021. *Construction News*. [Online]
Available at: <https://www.constructionnews.co.uk/supply-chain/structural-steel-and-rebar-prices-show-double-digit-price-rise-03-06-2021/>
[Accessed 03 June 2021].
- Subramanian, R. S., 2007. *Boundary Conditions in Fluid Mechanics*, New York: Department of Chemical and Biomolecular Engineering.
- Toro, A. D., 2012. *Computational Fluid Dynamics Analysis of Butterfly Valve*, s.l.: s.n.
- Walker, M. H. B.-B. M., 2011. *Composite Structures 2*. 2nd ed. s.l.:s.n.