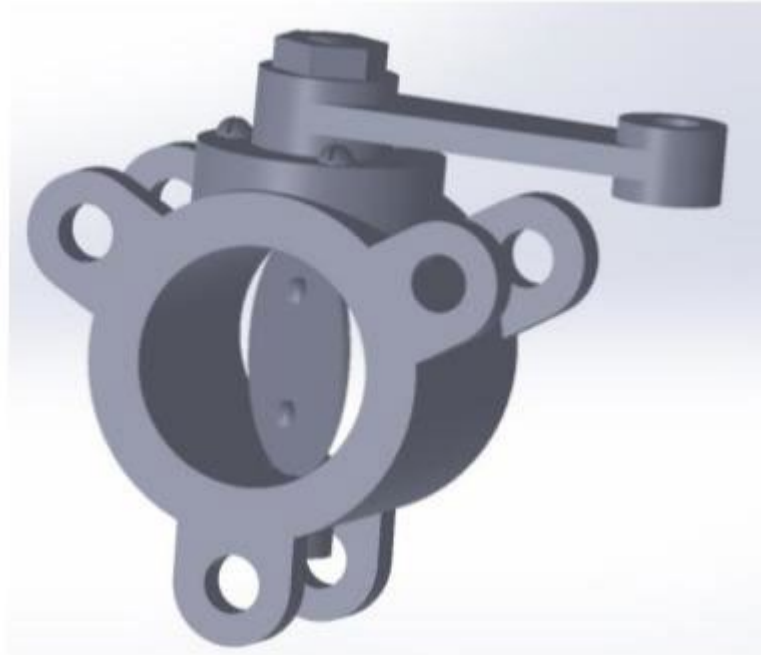


Structural and Fluid Analysis



By Daniel Lloyd Tubb

Introduction

We have been discussing flow fluid around objects and through pipes in class. The following report builds upon this and we have been set a task to complete. The following report includes a butterfly valve which is to be inserted into a pipeline that forms the outlet at a base of a 5m high storage tank that contains petroleum at atmospheric pressure. There are 5 questions that I was required to undertake in order to complete this report and these are as follows.

1. Discuss Reynolds number. Why is this important, how does it influence the flow around the butterfly valve and estimate what the Reynolds number is of the fluid flowing around the butterfly valve?
2. Discuss boundary flow around the butterfly valve and relate this to the separation and the turbulence around the valve, particularly the rivets that hold the valve onto the central shaft. Discuss why you think that valve has been designed like this and the cost implications of such a design.
3. This butterfly valve is to be manufactured from glass fibre reinforced plastic. Discuss the implications of this in terms of the performance of the valve. Relate this to the historical, current and future developments of such components. You should include reference to technical literature, industry standards and codes of practice.
4. Discuss what modelling techniques could be used to simulate the fluid flow through this valve. Discuss the advantages and the disadvantages of the tools highlighted.
5. During the development of this component, it is proposed that a prototype is produced and tested in a laboratory to understand the fluid flow through this valve and also to correlate it to the simulation carried out in task 4. Discuss how you think this experiment should be carried out and how the acquisition of data should be obtained and compared to the simulation.

In this report I have answered these questions to the best of my ability.

1)

The Reynolds number is a dimensionless number, used to distinguish between turbulent and laminar flow in a mode, and to predict its flow in different fluid conditions. The Reynolds number is determined by making inertial force and viscous force opposing each other so their importance in any given fluid situation can be evaluated. This will allow us to predict how the model will behave when fluid conditions are introduced. Inertial force is defined as density, speed, and length and viscous force is the dynamic viscosity of matter. By multiplying the three inertial forces and dividing by the viscous force the Reynolds number can be obtained. The following equation is used to determine Reynold's number:

$$\text{Re} = \frac{\text{Inertial Forces}}{\text{Viscous Forces}}$$

$$\text{Re} = \frac{\rho u d}{\eta}$$

ρ = density

u = velocity

d = diameter

η = dynamic viscosity

When the Reynold's number is calculated it can be determined what type of flow it is. There are 2 different types of flow, these are laminar flow and turbulent flow. When the Reynold's number is less than 2,000 the flow in a pipe is considered as laminar flow. If the Reynold's number is above 2,000 the flow in a pipe is considered as turbulent flow.

Laminar flow

The main feature of laminar flow is streamlined flow. The fluid flow will not be disturbed and the flow path will not have any vortex or cross flow. Even if the fluid layers do not cross, they will still flow at different speeds. The flow velocity in the center layer is the fastest, while the flow velocity in the outer layer is much slower. Characteristics of laminar flow:

- High viscous forces
- Low inertial forces
- High viscosity
- Low velocity
- Low length

Turbulent flow

Turbulence flow is seen as the chaotic and rough movement of particles through an area. There is a lot of friction between the boundaries of different layers. Molecules are scattered around in an irregular pattern and it is easy to find whirlpools and waves in the flow. A fluid in a turbulent state has a lot of kinetic energy in it. As long as this energy remains the flow will continue to be turbulent and irregular. Once the energy is used up the flow will change to a laminar state. Characteristics of turbulent flow:

- Low viscous forces
- High inertial forces
- Low viscosity
- High density
- High velocity

(Difference between laminar and turbulent flow, 2021)

(what is Reynolds number Labmate, 2021)

Estimate the Reynolds number of the fluid

$$\rho = 800 \text{ kg/m}^3$$

$$u = ?$$

$$d = 100\text{mm} = 0.1$$

$$\mu = 0.006$$

First of all, we need to find the velocity. To do this we can use Bernoulli's equation.

$$v = \sqrt{2gH}$$

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

$$5 = 5 \text{ meter height of the tank}$$

$$v = 9.9 \text{ m/s}$$

$$u = 9.9 \text{ m/s}$$

From this we can estimate Reynolds number:

$$Re = \frac{\rho u d}{\mu}$$

$$Re = \frac{800 \times 9.9 \times 0.1}{0.006}$$

The diameter of 100 mm or 0.1 is because there were issues with opening the assembly on solid works on my laptop. 100 mm or 0.1 is a 4-inch diameter where an online product is where an estimation of the diameter. Also, for the dynamic viscosity estimated that it's gasoline at 0.006. Petroleum has many different substances and broad I decided to choose this.

$$Re = 132,000, \text{ therefore the flow is turbulent}$$

2)

The butterfly valve is a flow control device used to adjust the fluid flowing through a section of pipeline. Because the valve is fully opened the disc rotates a quarter turn allowing fluid to pass through. The butterfly valve is bidirectional, but has a preferred flow direction. However, it is strongly recommended to install the valve along the preferred flow direction, as this will extend the life of the valve and reduce the operating torque. In this scenario the preferred flow is from the seat side towards the dome side. A Butterfly valve is a quarter-turn rotary motion valve used to stop, adjust and start flow. The butterfly valve has a disc mounted on a rotating shaft. When the butterfly valve is completely closed, the disc completely blocks the pipeline. When the butterfly valve is fully opened, the butterfly plate is at right angles to the flow of gas or liquid.

We must consider boundary flow conditions and separation with this butterfly valve. When the butterfly valve is closed there is no flow. When the valve is in process of opening there will be separation of boundary layers due pressure occurring which means the speed of the flow slows down due to this. As a result, the flow becomes turbulent and vortex begin to happen due to the pressure applied as the valve is opening. After the valve has completely opened the flow will transition into laminar as the flow will be continuous rate and not slowed down.

The reasoning behind the valve being designed like this are:

- Butterfly valve will be easy and fast to open
- Butterfly valve will have less space requirements
- Butterfly valve is relatively easy to maintain
- Butterfly valve is relatively inexpensive to built

(Butterfly valve factors, 2021)

(How Fluid Flows in Pipes — Accendo Reliability, 2021)

3)

It is suggested that the butterfly valve is to be manufactured out of glass fibre reinforced plastic. So, what is fibre reinforced plastic?

Fibre reinforced plastic composites consist of reinforcing fibers in a polymer matrix. The most common reinforcing fibre is glass fibre. This combination of plastic and reinforced materials can produce the strongest materials developed. Fibre glass reinforced plastic is an excellent material choice for the construction of chemical storage tanks, piping systems, instruments and other types of industrial processing equipment. The properties of fibre reinforced plastic materials are better to many traditional materials such as steel, in terms of chemical resistance and corrosion resistance. Very little maintenance and long product life this is what the well-designed fibre reinforced plastic equipment promises.

History and development of Fibre Reinforced Plastic

During the 1940's the first use of glass fibre reinforced plastic was used in the aircraft industry. Following that, years later it was used by non-military application in the marine sector proving fibre reinforced plastic to be a complete and new innovation and therefore completely changing the way ships are built.

Fibre reinforced plastic is constantly looking for new applications in the engineering industry with the development of resin technology ensures an exciting time for the future. This will see fibre reinforced plastics as a highly versatile and cost-effective alternative to metals.

Comparison to steel

Strength - Compared with steel Fibre Reinforced Plastic the strength is equal or better in some cases. People don't think of the word plastic and think it is as strong as steel. However, because glass fiber grating has greater flexibility, it has higher impact resistance than steel. Because steel is very hard it will not bend and will dent when subjected to a major impact. You don't need to worry about Fibre Reinforced Plastic and the impact, because it has no impact. All these strengths and weight are only a small part of steel, thus reducing installation and transportation costs.

Durability - Corrosion is also an area where the cost of Fibre Reinforced Plastic is reasonable because it is the biggest advantage over steel. Even without water steel is very susceptible to corrosion. Steel can be corroded by particles in the air such as salt or acid. This means that the service life in highly corrosive environments is very limited. With Fibre Reinforced Plastic the glass fibre grating will not corrode at all, so it has a longer service life than steel. In fact it can handle environments that are directly exposed to chemicals, acid, salt water, oil and many other common corrosives.

Cost - Despite the high cost of Fibre Reinforced Plastic it can be used for up to 20 years. This will give you a higher return on investment so you are taking advantage of the higher initial cost of Fibre Reinforced Plastic. Although the initial cost of steel is lower the cost is only the material itself, not the installation cost. Installation is where the overall cost of steel soars. Steel is heavy and requires many special machines to move and assemble steel structures. Fibre Reinforced Plastic is light in weight, requires only basic tools to assemble and can be assembled on site without additional costs. When you consider that

it is not only lighter, stronger and easier to assemble than steel you will completely rethink steel. Although the initial FRP cost is higher, it is indeed a smarter, cheaper, and longer-lasting investment.

Performance of glass fibre reinforced plastic butterfly valve

Since the butterfly valve is manufactured from glass fibre reinforced plastic the valve will be strong but light in weight. Since petroleum at atmospheric pressure flows through the butterfly valve, it is suitable for pressures up to 16 bar and the temperature range is -10°C to 110°C. The valve is made of glass fibre reinforced plastic which means it is lighter than a steel valve, so the operator can operate it safely and easily during installation. This lightweight material also minimises the energy consumed for transportation and installation. Glass fibre reinforced plastic has higher corrosion resistance, longer service life and more efficient use of energy and resources during operation. Compared with steel the valve provides a more cost-effective and sustainable solution.

(Material, 2021)

(Why Choose Butterfly Valves for Oil and Gas Applications?, 2021)

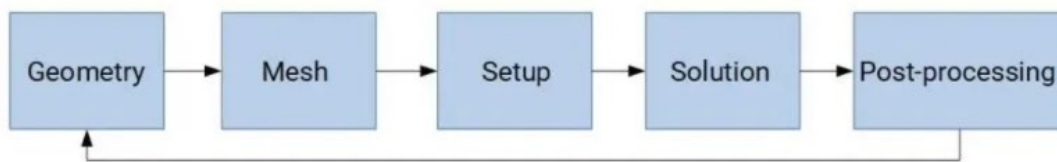
4)

There are a few modelling techniques that are used in the engineering world today to simulate fluid flow. One technique that's used widely is CFD modelling.

What is CFD modelling?

CFD or computational fluid dynamics modelling is the process of creating computer models to solve engineering problems involving fluid flow. A CFD model is a representation of fluid dynamics in a specific application, which is solved using numerical algorithms to obtain flow velocity, pressure, and other engineering interests.

A CFD modelling workflow can be split up into five stages. These five stages are Geometry, Mesh, Setup, Solution and Post processing. Figure 1 below:



Typical CFD modelling workflow

Geometry

The first step in the CFD modeling process is to define the geometry of the problem to be solved, this comes from a CAD model. Geometry can be included in the computational domain. With the external flow problem, the computational domain is usually the volume around the geometry of interest, which should have a sufficient size. On the other hand, with internal flow, the computational domain is represented by the extent of the geometry itself.

Mesh

To use numerical algorithms to solve the flow, the computational domain and geometry need to be used to create a computational grid. Generally, the meshing process involves dividing the volume in the computational domain. Within each unit, fluid flow equations will be solved to calculate flow characteristics such as velocity and pressure. These attributes are carried by the flow through the entire domain and affect the solution of each unit.

Setup

In order to obtain a flow solution, boundary conditions must be assigned to the surface representing the computational domain and geometry and an initial value must be assigned to the flow variable for example velocity or pressure in each unit. The initial conditions and boundary conditions are mathematical representations of actual flow conditions in practical problems.

Solution

Once a CFD model is fully defined mathematical problems can be solved through numerical algorithms. The solution starts from the initial conditions and evolve according to the boundary conditions. The rate of change of the solution in terms of flow variables such as pressure or velocity is called the residual. In the simulation process the residual of each equation should be gradually reduced to a relatively small number. This indicates that the flow solution no longer changes significantly and the numerical value has been reached.

Post processing

After a simulation is complete the CFD solution includes understanding the value of flow variables, such as velocity and pressure in each node of the calculation grid. These results are usually post-processed to obtain graphs and plots that the user can easily read and compare. Post-processing is an important part of the CFD modeling process because it allows understanding of flow into the design. Post-processing results can be used to determine improvements to the design, as well as to evaluate and compare different designs to determine the best design.

Advantages of CFD

- The simulations can be done over a short period of time.
- Data can be introduced early into the design phase.
- CFD simulations are not very expensive to run compared to experiments.
- Has the ability to simulate any physical condition.

Disadvantages of CFD

- Computing times may increase with large models.
- Some errors occur due to simple flow models.
- Turbulences can be modelled only with high degree of approximation.

(CFD modelling - IdealSimulations, 2021)

(Advantages of CFD | FEA services and consultancy. CFD and FEA company, 2021)

5)

Butterfly valves are pressure vessel that must meet strict requirements to withstand pressure without leakage. Its main body, cover and other key components must be free of cracks, loose air holes, slag inclusions and other defects that affect strength. There are several valve tests that can be completed throughout the production process. It is very important to conduct valve testing at every step from design to manufacturing, installation, operation and maintenance. However, the most important valve test is the quality test. You can perform multiple close visual inspections and valve-specific performance tests to find any defects and make corresponding adjustments. It can be put into use only after passing all tests. These are main valve tests that can be carried out for the butterfly valve:

Valve shell test

A shell test verifies the strength and integrity of the pressure-bearing structure of the valve. This is actually a pressure test where usually air, inert gas or water can be used as the test fluid. Pressure is applied to the assembled valve with closed ends. The valve should be partially opened and able to maintain the pressure for a certain period of time. The pressure should not be less than 1.5 times the maximum working pressure. No leakage is allowed.

Low/High pressure closure test

Perform a shut-off test to confirm that the leak passes through or through the closing mechanism of the valve. The closing test is performed after the valve body test is successfully completed. The valve is mounted on the test bench and the valve shall be completely closed. The inlet or outlet side of the valve should be subjected to hydrostatic pressure and the leakage should be measured on the other side of the valve. The more pressure you apply to the valve inlet, then you must measure the amount of leakage at the outlet. For low and high pressure tests, leakage through the disc, behind the seat ring, or shaft seal is not allowed.

Butterfly valves are usually used to control internal flow of compressible and incompressible fluids. Butterfly valves usually consist of a metal disc formed around a central axis, which serves as its axis of rotation. As the valve opening angle increases from 0 degrees (fully closed) to 90 degrees (fully open), fluid can flow through the valve more easily. The performance factors of the valve, such as pressure drop, fluid dynamic torque, flow coefficient, loss coefficient and torque coefficient is necessary for the fluid system designer to properly consider the system requirements.

With simulation results you could take pressure readings from the valve's opening angle and take increments starting from 10° up to 90°. With all the data being recorded it can be plotted on graphs for example.

(Valve Inspection & Testing | What is Piping, 2021)

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