

Tomos Blizzard

1402861

BEng Mechanical and Manufacturing Engineering

Kelvin Lake

Structural & Fluid Analysis

Designing A Butterfly Valve – Fluid Flow Assessment

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1.0 Introduction

During this I will be discussing a butterfly valve which will be inserted into a pipeline. This component forms the outlet at the base of a 5m high storage tank, containing petroleum at atmospheric pressure. I will discuss Reynolds number and its importance. I will also look at boundary flow around the valve and relate this to turbulence and separation. This product is to be manufactured from glass fibre reinforced plastic. I will look at the performance of this material for this component. There are many different modelling techniques which can be used to simulate fluid flow and I will look at the advantages and disadvantages of the tools highlighted. Finally, I will be discussing how an experiment should be carried out to test a prototype component. I will also look at how the data should be collected and compared to the simulation.

2.0 Reynolds Number

A dimensionless Reynolds number plays a massive role in predicting the patterns in fluids behaviour. The Reynolds number is known as Re . It is used to determine whether the fluid flow is turbulent or laminar. The Reynolds number is the main controlling parameter in all viscous flows where a numerical model can be selected with a pre-calculated Reynolds number. Reynolds number is made up of both static and kinetic properties, but it can be specified as a flow property. Strictly speaking, Reynolds number is the ratio of viscous forces and inertial forces. This helps to determine laminar flow from turbulent flow. (White, 2002)

Based on API 13D recommendations, if the Reynolds number is less than 2100 the flow is considered laminar but if the number is greater than 2100 the flow is considered turbulent. Flow in a pipeline consisting of liquid may have laminar flow. (Menon, 2015) says that this type of flow will move in layers, also known as laminations without causing turbulence. If we were able to see into a pipe and inject a dye into the fluid, the dye would flow in a smooth, straight line confirming laminar flow. If the flow rate was to increase, this would result in the velocity increasing causing the flow to change from laminar to turbulent flow with eddies and disturbances. This will also be able to be seen if dye was injected in a second time when the velocity has increased.

Normally, a butterfly valves main purpose is to control the flow rate. For our problem, we will need to look at the valve position in various angles as this will change the characteristics inside the valve. The angles of the valve will be 0° to 70° . The flow characteristics inside the pipe will change at the different angles. However, the valve geometry can be projected by the loss coefficient. When looking at the valve you have to consider the value of torque because changing the angle of the valve will impact on the flow capacity. This will increase the amount of pressure on the valves disk. The two types of torque are hydrodynamic torque and frictional torque. To investigate hydrodynamic torque, the volume flow rate, position of the valve disk and diameter of the pipe need to be set at different parameters. (Chaiworapuek, 2007)

To estimate the Reynolds number there were some assumptions which I had to make. These were that there were no frictional losses, the petroleum was at 20 degrees and the valve was fully open. Below are the calculations.

$$P_1 + \frac{1}{2} \rho V_1^2 + \rho g h_1 = P_2 + \frac{1}{2} \rho V_2^2 + \rho g h_2$$

$$0 + 0 + \rho g h_1 = 0 + \frac{1}{2} \rho V_2^2 + 0$$

$$\frac{1}{2} V_2^2 = g h_1$$

$$V_2^2 = 2 g h_1$$

$$V_2 = \sqrt{2 g h_1}$$

Using the formula above we can calculate the velocity when the valve is fully open. This is;

$$V_2 = \sqrt{2 \times 9.81 \times 5}$$

$$V_2 = 9.9 \text{ m/s}$$

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

$$Re = \frac{800 \times 9.9 \times 0.194}{0.006}$$

$$Re = 256 \times 10^3$$

3.0 Boundary Flow

Boundary flow in fluid mechanics is a thin layer of flowing gas or liquid. An example of this is a fluid or gas being in contact with the inside of a pipe. These fluids are put under shearing forces on the boundary layer. There are a number of velocities which exist around the boundary layer which vary from zero to maximum velocity. This will only occur if the fluid or gas is in contact with the surface of the pipe. Another example of boundary flow is an aeroplane wing. The boundary are normally thinner at the front of the wing, where as the boundary layer is thicker at the back end. The flow is generally laminar at the front end of the wing but it changes to turbulent as it reaches the back of the wing. (The Editors of Encyclopedia Britannica, 2020)

Butterfly valves are used to regulate the flow of multiple fluids through a pipe like water, oil and petroleum. (Jeon, 2010) says fluids are best controlled using the butterfly valve as there are multiple positions which can be selected to determine the flow of the fluid. If the valve is fully opened, it will turn the disk so there is almost no restriction within the pipe.

There are four main components which make up a butterfly valve. These are the butterfly valve body, disk, stem and seat. The body of the valve is generally fitted between two pipes. The disk is used to control the flow of the fluids travelling through the pipes. The disk designs can change depending on the system and fluid they are being fitted to. The stem is generally a shaft which is the link between the disk and shut off valve. This shaft is protected from the water flow as it is held in a neck of the butterfly valve. The final part of the butterfly valve to discuss is the seat. This seat is what combines with the disk to create an interference fit when closing the valve. This seat can be bonded to the body or it may be pressed in. (Solken, 2008)

A butterfly valve is considered to be bi-directional but they do have a preferred direction of flow. This is why it is advised that the valves are installed in the preferred direction of flow. This is what ensures the longevity of the butterfly valve. It will also reduce the operating torque. When the butterfly valve is being operated, it is used to stop, regulate and start the flow of fluid. When the valve is closed it will completely block the pipe causing the fluid to stop. The disk can then be turned in line with the pipe which gives no restriction to the fluid. (Belimo, 2014)

The valve has been designed in this way for the following reasons. The design is compact so it doesn't take up much space compared to others, like a gate or globe valve. It is light in weight and also quick to open when releasing the gases or fluids. They are available in various sizes to suit a variety of systems. They also have a low-pressure drop and high-pressure recovery. Finally, they offer a bubble tight service. All of these factors make the butterfly valve cost effective and it also makes the valve versatile for many different applications.

The disadvantages of the butterfly valve are cavitation and choked flow are a concern when installing and there is always a portion of the disk which is in line with the flow of the gas or fluid. This is why there is always a pressure switch across the valve, this cannot be solved with set up. (Menon, 2015)

4.0 Manufacturing Material

A butterfly valve has been used since the 18th century. A butterfly valve was used by James Watt when he developed his steam engine prototypes. During this time, butterfly valves were very large and struggled with high temperatures. Since advancements have come in with technology and material manufacturing it has allowed these butterfly valves to become smaller and withstand much hotter temperatures. After World War II butterfly valves seen a major advancement which was synthetic rubbers. This allowed the seals of the valve to become much more durable and effective. (Stoneleigh Engineering Services, 1987)



Figure 1 - (Hemphill, 1996)

The butterfly valve in question is going to be manufactured from glass fibre reinforced plastic. This type of material is used in almost all advanced engineering structures in today's world. These structures include aeroplanes, boats, cars, chemical processing and civil infrastructure. A position where glass reinforced plastic is used more frequently now is electrical insulation materials, like power distribution systems. To prevent these systems being compromised a resin system which is moisture resistance must be used to prevent the system being compromised.

When comparing glass fibre to steel there are many differences but below, you will be able to see the positives and negatives between the two types of materials when used in making a butterfly valve.

Strength

When people think of steel, they see it as being an incredibly strong material which can't be matched by plastics but this is where people are wrong. Glass fibre plastics are relatively equal if not stronger than steel. This is down to glass fibre having a greater flexibility which gives it a higher impact resistance than steel. There are massive advantages to this because glass fibres are lighter yet, stronger. This saves a massive cost in transportation of a product and installation of larger products easier.

Safety

When looking at accidents within the workplace you can see that in an industrial environment the accidents are far more frequent than in an office environment. Accidents within industrial settings can also be more severe if they occur. When looking at the HSE, it lists structural, construction and fall protection as the most common compliance failures. This isn't done intentionally but it all comes down to poor designs and material choices.

With fibre glass plastics, there is no need to be concerned about structural integrity, durability, shock hazards or corrosion. This is why we are seeing fibre glass plastics being used more and more. They do not conduct electricity; they don't break down from corrosion and it is equal or stronger in strength to steel. The biggest draw to fibre glass plastics is the weight of the product. When compared to steel it is a fraction of the weight.

Durability

The biggest draw to fibre glass plastics over steel is its resistance to corrosion. A fibre glass product can last well over 25 years in similar environments which see's steel failing from corrosion in 10-15 years. The places when fibre glass plastics are being used more and more are in oil refineries. As this type of work is very corrosive, fibre glass plastics are used more to prevent failure. Fibre glass can resist direct exposure to acid, blood, oil and many more corrosives.

Cost

If you directly compare steel and fibre glass plastics initial costs, steel will always be cheaper. The reason fibre glass plastic is being used more now is because regardless of the initial cost of steel being cheaper, it is heavy and can generally be expensive to install. Fibre glass plastics are the opposite. They are light and cheaper to install. It will also last much longer than steel due to its resistance to corrosion. This is why companies are now investing in a slightly more expensive product at the start but having confidence that the product will last much longer than a steel product. This makes the initial cost seem much better when look at as a long-term option. Finally, when shipping a fibre glass product, the weight is a fraction of what a steel product would cost. This makes shipping this product around the world much cheaper and easier. (Engineering360, 2020) (Song, 1996)

5.0 Modelling Techniques

There are a variety of different modelling techniques which are available across a number of different platforms but the most common and generally seen as user friendly is Solidworks Flow Simulator. This simulator allows you to select a number of different parameters. Solidworks Flow Simulator is a mid-range fluid flow analyser which can look into liquids and gases. This flow simulator is capable of analysis of instruments from a variety of different fields such as electrical equipment, medical, automotive and aerospace. Another benefit to Solidworks Flow Simulator is its ability to measure fluid flow along with thermal analysis when they are tied together. (Ramlan, 2020)

The flow simulation has a number of advantages when looking at what you can do with the programme. To list a few;

- Internal and external flows
- Wall roughness
- Automatic laminar/turbulent solution with transition
- Radiation
- Non-Newtonian flows – This is used for viscous fluids like blood.
- Porous media
- Cavitation
- Relative humidity

When looking at the limitations of the Solidworks flow simulation, they are limited. You have to be looking at very specialised areas to find something this programme can't do. These limitations are;

- Phase Change – The package struggles to manage materials which transform from gas to liquid or solid to liquid.
- Co-existence of Different Phases – The flow simulator can't hold a liquid and a gas in the same area. The only way this can work is if they're in separate cavities or different volumes.
- Combustion – Chemical reactions can't be performed.
- Moving Bodies – Flow simulator can't simulate objects moving and displacing the fluids or gases as they move. (Computer Aided Technology, 2021)

Another modelling application is Onshape. Onshape is a cloud-based application. This allows you to access your models or drawings from you laptop, tablet, phone at any time. Whereas Solidworks is downloaded to your PC/Laptop but only available on that device. Solidworks is a more powerful tool down to this reason but in the current world we live in, everything is needed on the go and easy accessibility. This is where Onshape is offering a great working programme but also access from the cloud. The major advantages of Onshape are;

- Collaboration with multiple users
- No need for an expensive computer
- Faster to start parts/assemblies
- Native revision tracking
- Access from multiple locations

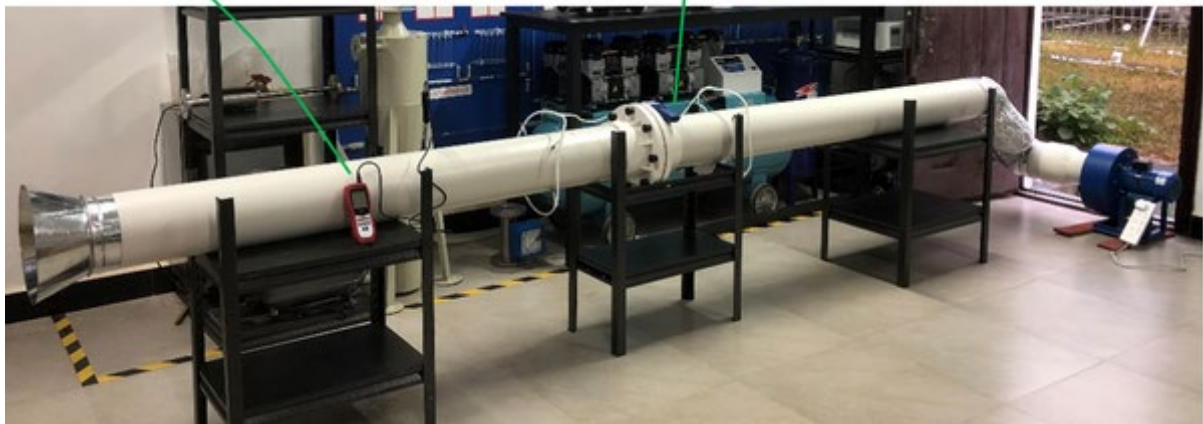
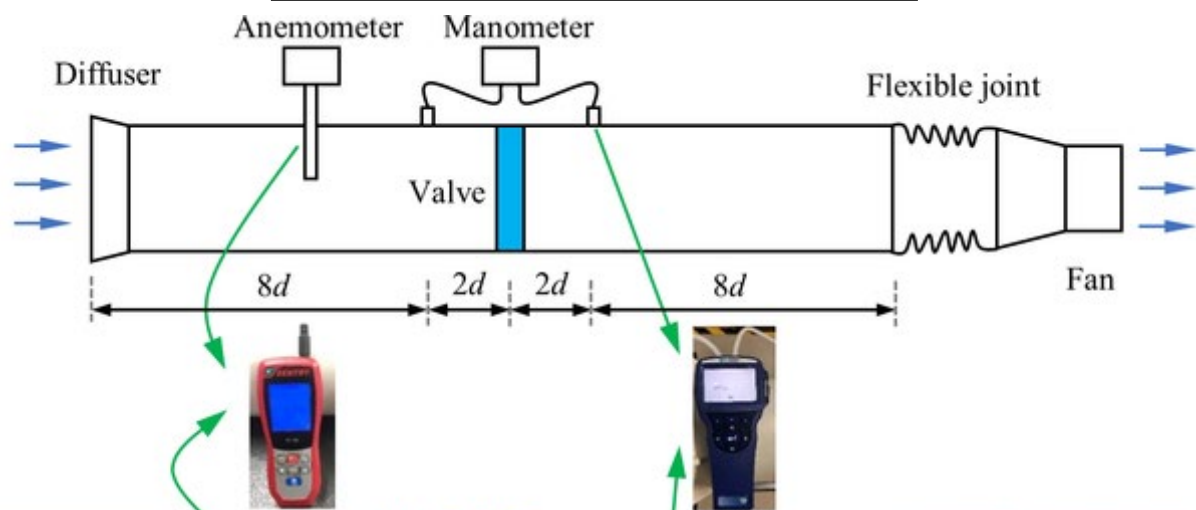
The negatives are more evident in this programme because it isn't run from a dedicated device which holds much more power than the cloud is able to currently offer. These negatives are;

- Limited functionality
- Internet connection required
- Limited methods of analysis
- Browsers limit the number of shortcuts available.

6.0 Development of The Component

To carry this experiment out with fluid will be very difficult so for the purpose of the experiment a gas will be used. This experiment will be used to validate the simulation which took place previously. The experiment will be made up of several different parts. The parts which make up this experiment are a diffuser, wind pipe, air-ring flow regulating valve, flexible joint and a fan. The fan will be the source of air at the end of the flexible pipe. This fan will be controlled by a frequency inverter. To measure the airflow within the pipe an anemometer is connected. This will give the airflow readings from the fan. The next component which will be fitted in-line will be the manometer. The manometer will be fitted before the butterfly valve and after the butterfly valve. The manometer will have four connection points, two of these connections will be before the butterfly valve and two are fitted after the butterfly valve. To calculate the pressure drop, it was tested five times and the average of these values which sets a stable pressure valve. The diameter of the pipe is 20cm. (Toro, 2015)

(Shixian, 2021) – Experimental Method Schematic



The photo above shows an example of the experiment which will be recreated to complete the experiment for the butterfly valve. This experiment has been used previously which is proven to work. Once the experiment has been carried out it will be time to look at the results. The results will be made up of the numerical and experimental values. The anemometer will detect the air-flow when the butterfly valve is fully open and partially open and closed. Once the values have been documented in a table, they can be compared to the simulation results. (Takeyoshi, 1995)

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