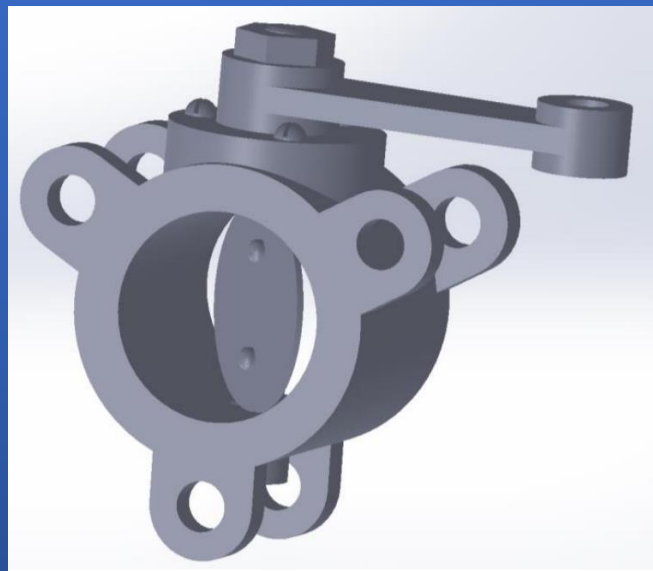


DESIGNING A BUTTERFLY VALVE: FLUID FLOW ASSESSMENT



Owen David Bayliss (1708437) Word Count - 3023

ACMA6010 Structural and Fluid Analysis

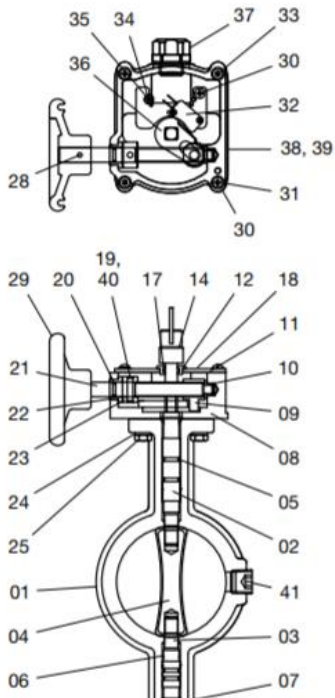
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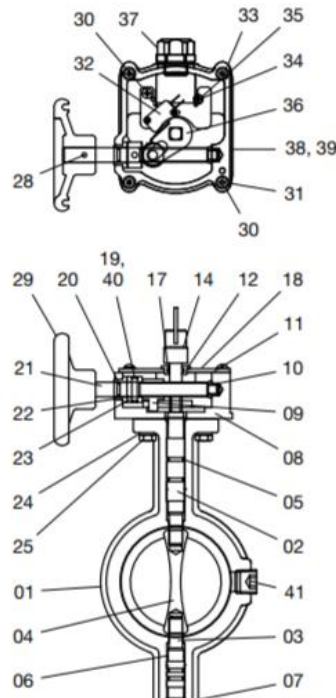
1. Introduction

The purpose of this report is to determine and discuss the fluid flow around an object, our object in this instance is a butterfly valve and more specifically the part that will be crucial in examining the fluid flow will be the disc (04) of the butterfly valve, Refer to additional technical data sheet for a Tyco Model BFV-300 Butterfly valve for components names and sizes, however please note I am only using this Butterfly valve data sheet for reference, as a tool when I am referring to certain components and parts of the Butterfly valve in my task. The task outlined in this report is to discuss and expand upon the topic of fluid flow around an object and through an open pipe. The object being the butterfly valve which has been fitted to a pipeline at the outlet on the bottom of a 5m storage tank, the tanks contents being petroleum. These are all the basic elements that is given to me in the project brief to properly cross examine and test fluid flow. In this report I will use techniques and theorems to explain and discuss upon the fluid flow around the butterfly valve through the pipe of the tank. I will split the problem into 2 parts, the fluid flow from the tank through the pipe applying Bernoulli's equation to find the volumetric flow rate and the mass flow rate of the petroleum through the valve making several assumptions and then to expand on this I will use the information that I have found and then applies this to the next part of my problem. This problem being the fluid flow around the butterfly valve and how it affects boundary flow, turbulence, and frictional losses. I will examine the surface of the disc and the components that are used in its construction and how these may or may not affect the fluid flow in terms of turbulence. Applying the Reynolds number when examining the flow around the surface of the disk. In my method I will expand upon this point of Reynolds number, as to what it is, How I devise this number and how I apply it to my studies and equations and what this will tell us about the component and how it affects fluid flow. I will continue to expand upon fluid flow and more specifically boundary flow, examine the disc of the butterfly valve and analysing how it will have an effect of aspects such as velocity, pressure and any separation or turbulence that may occur.

No.	Part	Material	Qty.	No.	Part	Material	Qty.	No.	Part	Material	Qty.
01	Body	ASTM A-536	1	15	Spring Pin	ASTM A-228	1	30	Bolt (Round)	ASTM A-167	3
02	Upper Stem	AISI 410	1	16	Indicator	ASTM A-619	1	31	Plate Washer	ASTM A-167	4
03	Lower Stem	AISI 410	1	17	O-Ring	NBR	1	32	Switch Assembly	—	1
04	Disc	EPDM	1	18	Cover Gasket	Paper	1	33	T/R Bolt	ASTM A-307	2
05	O-Ring (P12)	EPDM	4	19	Spring Pin Ø5x1T x25	ASTM A-228	1	34	Tapping Screw ST3.5 x 7.5	S10C	1
06	Oilless B/R (MB1410)	—	4	20	O-Ring (P10)	EPDM	1	35	Tooth Washer 4#	S10C	1
07	End Cap 2-1/2-4 Inch	EPDM	1	21	Worm Shaft	AISI 410	1	36	Lever	ASTM A-619	1
08	Gear Box	ASTM A-536	1	22	Bushing (1)	FD-0205-45	1	37	Connector	—	1
09	Traveling Nut 2-6 Inch	Bronze	1	23	Collar	FD-0205-45	1	38	Sticker	—	1
	Segment Gear 8-12 Inch	C3604BD	1	24	Spring Washer	ASTM A-167	4	39	Sticker	—	1
10	Bushing (2)	FD-0205-45	1	25	Hex Bolt M8 x 20L	ASTM A-167	2	40	Spring Pin Ø3x0.6T x25	ASTM A-228	1
11	Cover	ASTM A-619	1	26	Hex Bolt M8 x 25L	ASTM A-167	2	41	Headless Plug 3/8 NPT 2-3 Inch	ASTM A-307	2
12	Bushing	Fe	1	27	Gasket	Paper	1		Headless Plug 1/2 NPT 4-12 Inch		
13	Headless Wrench Bolt M5 x 7L	ASTM A-307	1	28	Spring Pin Ø4x0.8T x35	ASTM A-228	1				
14	Stem Housing	Fe	1	29	Handwheel	ASTM A-536	1				



**BFV-300 Normally Open Valve
Supervisory Switch Arrangement**



**BFV-300C Normally Closed Valve
Supervisory Switch Arrangement**

**FIGURE 2
MODEL BFV-300/BFV-300C GROOVED END BUTTERFLY VALVE
ASSEMBLY**

2. Method

To begin this examination of the fluid flow around the disc of the butterfly valve I had to fully understand what will be happening throughout the assembly from the beginning in the storage tank itself through the outlet on the tank to the pipe, through the pipe and then through the butterfly valve itself. To do this I have chosen to split my assessment into two parts. The first being the fluid flow from the storage tank, through the outlet and then through the pipe and secondly from the pipe through the open butterfly valve.

For the first stage of my assessment, I will be examining the fluid flow from the storage tank through the outlet and through the pipe. However before beginning my analysis there are multiple assumptions that I need to make in order to complete my calculations. These basic assumptions were not previously outlined in the project brief. In the vague project brief I was only told that the 5m storage tank contains petroleum at atmospheric pressure. To complete my calculations using Bernoulli's Equation, I would need to know the area of the tank, what kind of petroleum in question and therefore what is the density of the petroleum? For the area of tank, I assumed that the shape is the same as that of a water storage tank for a sprinkler system this is cylindrical tank where the diameter is usually parallel with the height. I made this assumption since I have some experience in dealing with tanks of this shape so can guess what the diameter and area would be. For the tank in question, I chose to keep the diameter in parallel with the height of 5m. So, the petroleum storage tank will be 5x5m. As for the petroleum itself I have selected Arabian light crude oil. This type of crude oil is high sulphur produced in the middle east (Fitzgibbon, 2021). I have chosen to use this as it is primarily refined in most European refinery's (Fitzgibbon, 2021). Therefore, it would be a type of crude oil that I would most likely see in this country. Knowing what type of crude oil, I am using in this task, I am then able to find the density in order to express Bernoulli's equation to explain fluid flow. The density of the light Arabian crude oil is 800kg/m^3 (U.S. Energy Information Administration, 2021). Applying what I know now to Bernoulli's Equation I am able to find the volumetric flow rate and the mass flow rate for the petroleum passing from the tank into the pipeline. This key information will be crucial when working out the Reynolds number and viscosity of the petroleum as it travels around my butterfly valve. Continuing on from discussing how the petroleum will move about the butterfly valve I will discuss boundary and fluid flow; from my Reynolds number estimation I will be able to determine whether the fluid flow is laminar or turbulent and to what effect this will have on the disc of the butterfly valve and the boundary flow around it. Then examining the butterfly valve disc itself and examining how it has been constructed and from what material I will determine as to what effect this will have on our final flow parameters. Also, I will propose how you would test such a component under a test environment using pitot tubes and manometers.

3. Bernoulli's Principle

Bernoulli's Principle (shown here on the right side of the page) is a theorem and equation used throughout fluid dynamics and thermodynamics to test and analyse flows of fluid and gases around and through an object. Bernoulli's equation in its simplest form is "Pressure Energy + Kinetic Energy + Potential Energy = Constant" however when finding the fluid flow from one point to another, Bernoulli's equation would be presented as shown above on the top right of the page.

Taking what I already know from the project brief and from making several assumptions in order to complete my equation I can apply Bernoulli's equation to gain a better understanding of fluid flow through the outlet on the tank and through the pipe. I will first create a free body diagram of the tank and the outlet via the means of AutoCAD and base all my equations on this. Now that I have completed the FBD I can introduce Bernoulli's equation and therefore the assumptions and conditions that are needed in order to properly understand the principle. These assumptions are as followed,

- There is a steady and streamline flow present (TecQuipment. 2019).
- The density of the fluid is constant.
- There is minimal friction in the flow between fluid and object/pipe.
- The change in the heat transfer, temperature and work all equal 0.

From our problem I can make all these assumptions from simply examining what we already know and what is present from my FBD, beginning my calculation I will first present Bernoulli's equation in this format as I will assume there is no energy and temperature loss.

$$P_1 + \rho g z_1 + \frac{1}{2} \rho u_1^2 = P_2 + \rho g z_2 + \frac{1}{2} \rho u_2^2$$

Continuing, I will remove the pressure and kinetic energy from the equation. The potential energy is present as it does not change from point 1 to point 2 and the kinetic energy is removed as the surface area in point 1 is massive compared to that of point 2, so therefore this means that we can remove this from the equation. Leaving me with this,

$$P_1 = P_2 + \frac{1}{2} \rho u_2^2$$

Next I will simply rearrange the equation,

$$P_1 - P_2 = \frac{1}{2} \rho u_2^2$$

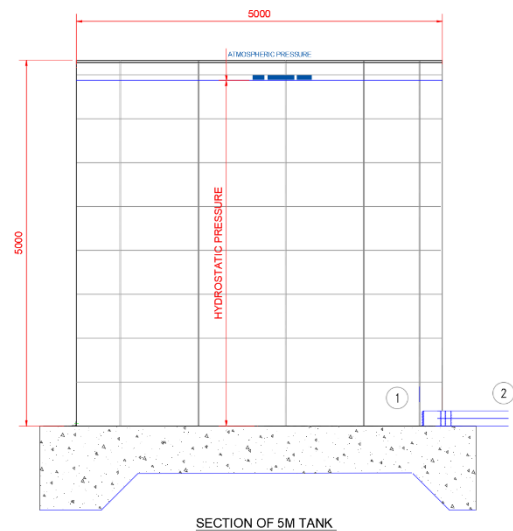


Figure 1 Free Body Diagram

As previously stated in the brief and what I have observed in my free body diagram the pressure difference is the hydrostatic pressure as the tank is stored at atmospheric pressure. So therefore,

$$P_1 = \rho gh$$

$$P_2 = p_{atm}$$

Substituting these two factors back into our previous equation we get,

$$(\rho gh + p_{atm}) - p_{atm} = \frac{1}{2}\rho u^2$$

Continuing, we will remove “ p_{atm} ” from either side of the equation as they will cancel each other out.

$$\rho gh = \frac{1}{2}\rho u^2$$

As density is present on both sides of the equation that can be removed.

$$gh = \frac{1}{2}u^2$$

Finally rearranging this equation, we are able to estimate the volumetric flow rate from the storage tank through the outlet at the bottom.

$$u = \sqrt{2gh}$$

$$u = \sqrt{2} \times 9.8 \times 4.999903$$

$$u = 9.899 \text{ m/s}^{-1}$$

Taking the flow rate we can now find the volumetric flow rate,

$$\dot{V} = uA$$

$$\dot{V} = 9.899 \times (\pi r^2)$$

$$\dot{V} = 0.03 \text{ m}^3/\text{s}$$

As I already know the density of the petroleum from previous research, I am able to work out the mass flow rate,

$$\dot{M} = \rho \dot{V}$$

$$\dot{M} = 800 \times 0.03$$

$$\dot{M} = 23.648 \text{ m}^3/\text{s}$$

4. Reynolds Number

When discussing the fluid flow around the butterfly valve it is crucial that we examine the Reynold number and to what affect this will have on the part and what will happen regarding the velocity, pressure and friction. The Reynolds number is a unitless number that portrays how an easily object can move through a certain atmospheric pressure in a gas or fluid, the higher the Reynolds number then the easier it is for object to move through the liquid or gas but the Reynolds number can change depending on the object even if the fluid or gas remains the same. This phenomenon is crucial when working with the Navier Stokes equations and its primary use is to identify whether a flow is laminar to turbulent. However, you should not be mistaken in thinking that Reynolds number is a single unchanging number, Reynolds number depends on many different factors, the Reynolds number will change depending on factors such as, the objects shape and velocity, the mass of the gas or fluid that is acting against the object and most importantly the viscosity of the object and how much it well compresses or changes shape under pressure (Vila, A., 2009). Thus, when relating and recognising these key features in our fluid flow experiment you may question how this may come into discussion as the butterfly valve is not under such strains as the fluid is flowing around the object and not the object moving through it, this does not analytically matter, the forces and fluid flow will still interact with the butterfly valve the same as if we were passing the butterfly valve through the petroleum and the same velocity and pressure. Reynolds number is critical when analysing laminar flow and turbulence produced by an object (Vila, A., 2009).

When finding the Reynolds number within our problem one of the most important factors that needs to be determined is the viscosity both kinetic and dynamic. This can be very difficult however, when finding the viscosity of light oil as the viscosity may change due to temperature and pressure. Whilst undergoing basic research on y components early on in my studies I was able to find the kinematic viscosity of Arabian Light Crude Oil at 20°C, this was another assumption I must make when

Crude Oil	Kin. Viscosity [mm ² /s] at Temp.	API Gravity °API
Arabian Light	10.7 at 20 °C	34.2
Bonny Light	2.90 at 50 °C	35.4 ... 35.8
Boscan	11233 at 100 °F	10.1
Brent	2.86 at 50 °C	37.9 ... 38.2
Escalante	307 at 38 °C	39.6
Kutubu	2.1 at 20 °C	44
Tia Juana Heavy	88.6 at 100 °F	12.3
Tia Juana Light	8.8 at 100 °F	31.9
West Texas Intermediate	4.9 at 20 °C	39

Showing 1 to 9 of 9 entries

1

Figure 2 U.S. Energy Information Administration, Genesis Group, USA, Chevron Crude Oil Marketing, Exxon Mobil, AMSA-Australian Maritime Safety Authority

conducting my calculations (oil is kept at room temperature). Now that I know the kinematic viscosity, I can use this and the density to find the dynamic viscosity which is crucial when finding the Reynolds number. The viscosity of fluid and how the molecular structure of the object is what produces a boundary flow layer. I will continue on to estimate my Reynolds number in the next area of my report.

5. Reynolds Number – My Calculation

Finding the Reynolds number for any fluid flow problem is difficult unless you already have the pre-determined values such as kinematic viscosity, density, fluid velocity and most importantly dynamic viscosity. As these were not value that I already had, major research was needed in order for me to begin to complete this calculation and interpret this into our free body diagram to begin to expand upon fluid flow about the boundary layer (Vila, A., 2009). As previously stated there have been assumptions that I have been made to make throughout this process and one of those has been, as to what temperature the petroleum been stored at, the most logical decision for this was 20'c as the tank is being stored at atmospheric pressure. Using the table shown in figure 2 I can see that the kinematic viscosity of Arabian crude oil at 20'c is, 10.7 mm²/s. The formula for Reynolds Number is shown below.

$$Re = \rho \cdot u \cdot dh / \mu$$

Where,

ρ =Density

u =Velocity

dh =Hydraulic Diameter

μ =Dynamic Viscosity

Next I will take this kinematic viscosity and density (that I already know from previous) and calculate the dynamic viscosity.

$$\mu = \rho \cdot \nu$$

In the above equation “ ν ” is kinematic viscosity,

$$\mu = 800 \cdot 10.7$$

$$\mu = 8560 \text{ pa.s}$$

Now I know my dynamic viscosity I can substitute this into my Reynolds number formula. However, first before I do this, I must convert my dynamic viscosity into a more suitable format in order for it to work in the equation. To do this I will simply divide the figure by 1000. Continuing with my equation,

$$Re = \rho \cdot u \cdot dh / \mu$$

$$Re = \frac{800 \cdot 0.008 \cdot 0.008}{8.56}$$

This low Reynolds number indicates that the flow is laminar. Meaning that the fluid will travel past our component in a uniform laminar flow and not turbulent.

8

0

0

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9

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8

6. Boundary Flow - Glass Fibre Reinforced Plastic Butterfly Valve

From what I have found when discussing Reynolds number and completing the calculations of an estimate is that the flow through the butterfly valve is laminar flow and not turbulent (Vila, A., 2009). This meaning that the velocity of the fluid is low and the flow is uniform a stream line (Encyclopaedia Britannica. 2021) . There are 3 types of boundary flow, laminar, turbulent and free stream flow. The boundary layer is where the velocity is 0. As you can see from figure 4 when laminar flow is present the velocity in the boundary layer moves in a uniform pattern until it meets the surface of the object, unlike in a turbulent flow where the fluid flow is completely erratic and unsteady (Hall, N., 2021. Boundary Layer). As the fluid flows around our butterfly valve, boundary flow dictates that we will lose kinetic energy, if we lose kinetic energy then the velocity will increase. As the velocity increases through our pipe and butterfly valve the pressure decreases. If we examine the assembly of the butterfly valve it is clear that the assembly between the disc and the rotating closing valve is actually held together via rivets. This has a substantial affect on the fluid flow within our system as now the surface of the disc of the butterfly valve is no longer a smooth and even, the introduction of the rivets will cause a larger separation streamline. This separation streamline will leave a larger wake than what would previously have been left if another joining mechanism had been used such as producing the component via a moulding method, this would reduce the probability of disturbance and separation in the boundary flow (Fitzpatrick, R., 2021). As there is a larger wake being produced, there will now be a larger drag coefficient and therefore turbulence produced in the flow stream behind the disc. This is clearly shown in figure 5, as you can see the separation point has occurred on the obstacle, this translates as the rivet in our assembly, and this has produced a large wake (Fitzpatrick, R., 2021). As our component is being produced out of glass fibre reinforced plastic this will mean that the Reynolds number for the butterfly valve may change as glass reinforced fibre plastic is not a high viscous material so friction and therefore potential energy loss is low. Glass fibre reinforced plastic is a very strong and long-lasting material, it is very durable, and production of glass fibre reinforced plastic is very cheap however there is some sustainability and environmental issues surround glass fibre reinforce as the production can be very damaging and toxic for the environment.

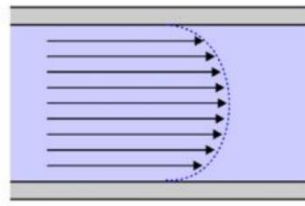


Figure 3 Laminar vs Turbular Flow Smith, M., 2021

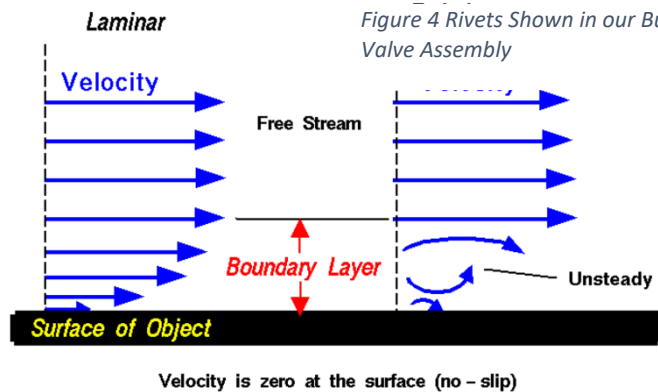
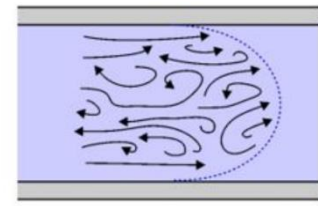


Figure 4 Hall, N., 2021. Boundary Layer

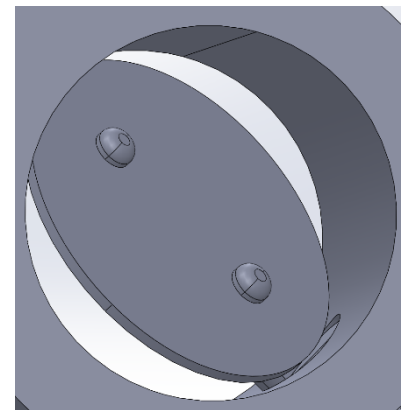


Figure 5 Rivets in our Butterfly Valve Assembly

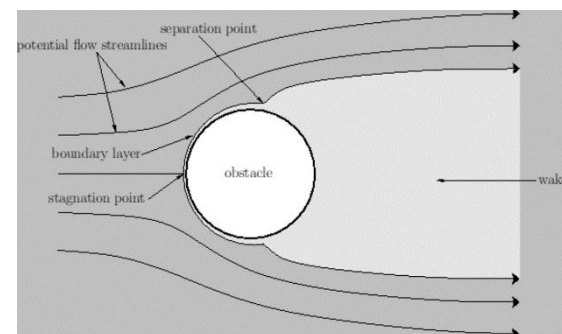


Figure 6 Fitzpatrick, R., 2021

7. Conclusion

Overall, at the beginning of this report I wanted to focus on and expand upon the fluid flow around the butterfly valve, starting at the beginning with the storage tank through the 194mm outlet at the bottom through the adjoining pipeline and through the GFRP Butterfly valve. Explaining how the fluid would interact with the valve and how the valve would interact with the petroleum. Through the introduction of Bernoulli's equation, I was able to determine the velocity, volumetric flow rate within the valve and the mass flow rate. This gave us a much broader knowledge on what was happening within the pipeline and more specifically gave me the tools in order to determine and make an evaluation of the Reynolds number, this intern advised me on whether the flow was laminar to turbulent.

Ultimately throughout industry a project streamline is paramount, and a timescale must be met in order to allow for a productive and successful project, therefore I believe in the design and production of butterfly valve such as this, this process of hand calculation and assessment is not the most productive option, the most productive option would be using digital finite element analysis software, this would provide you with more reliable and finite results. Also going down a more digital route would be more cost effective, although software packages and their licenses can be very expensive, in the longer term it is more cost effective and reliable than having to conduct a full investigation into each component.

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