



Prifysgol Cymru

Y Drindod Dewi Sant

University of Wales

Trinity Saint David

Module: Structural & Fluid Analysis

Module code: ACMA6010

Name: Rhys Jones

Student Number: 2014499

Lecturer: Kelvin Lake

Internal verifier: Rob Goodson

Assignment title: Designing a butterfly valve fluid flow assessment

Submission deadline: 30/07/2021

SUMMARY

In this assignment report I have discussed many topics to consolidate what I have discussed during my lectures. The topics in this report include Reynolds number, butterfly valves, fluid and boundary flow, glass fibre reinforced plastic, modelling techniques and a potential experiment that can be carried out on a butterfly valve prototype. Lastly, I concluded my report by stating how it went and any difficulties I came across.

TABLE OF CONTENTS

Summary.....	2
Introduction	4
Task 1.....	5
Reynolds Number	5
What is Reynolds Number?.....	5
The Importance of Reynolds number.....	5
Reynolds number calculation formula	5
Laminar, Transitional and Turbulent flow	6
Estimated Reynolds number of the fluid flowing around the butterfly valve.....	6
Task 2.....	7
Boundary flow around the butterfly valve	7
Why has the butterfly valve been designed like this?	7
Historical testing of GRP butterfly valves	8
Cost implications of the Butterfly valve design	8
Task 3.....	9
Implications of the butterfly valve being manufactured from GRP	9
Standards when manufacturing the butterfly valve.....	10
Task 4.....	11
Modelling techniques to simulate fluid flow	11
.....	11
CFD Advantages	12
CFD Disadvantages.....	12
Scaled down prototype model advantages	13
Scaled down prototype model disadvantages.....	13
Task 5.....	14
Experiment to compare to the simulation	14
Experiment Procedure	14
Experiment Discussion.....	15
Conclusion.....	16
Bibliography.....	17

INTRODUCTION

In this assignment I will be consolidating what we have been discussing during our structural and fluid analysis lectures about fluid flow around an object and through a pipe. The assembly I will be focusing on 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, which contains petroleum at atmospheric pressure. Throughout the assignment I will be carrying out several tasks to build upon the knowledge I have gained throughout this academic year to help consolidate what we have been discussing in class. Some of the tasks will involve discussing Reynolds number, boundary flow around the butterfly valve, implications of this in terms of the performance of the valve, what modelling techniques could be used to simulate the fluid flow and the advantages and disadvantages of the tools discussed.

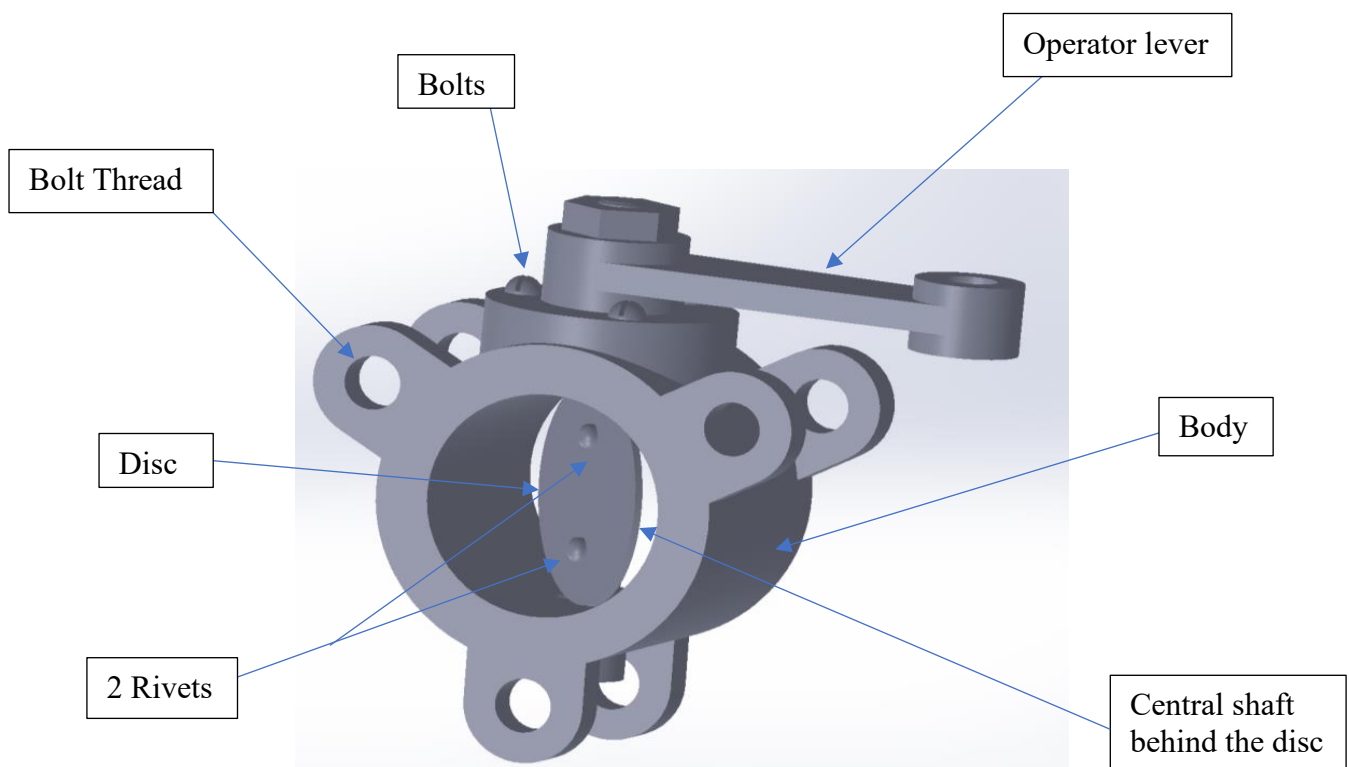


FIGURE 1. THE BUTTERFLY VALVE ASSEMBLY I WILL BE FOCUSING ON IN THIS ASSIGNMENT

TASK 1

REYNOLDS NUMBER

WHAT IS REYNOLDS NUMBER?

The Reynolds number is the ratio of inertial forces to viscous forces, and it is a dimensional number, this meaning it has no units. It is named after British scientist Osborne Reynolds who popularized it in 1883 (Khan, 1987). It is used to put the fluid systems into different categories, in which the effect of viscosity is important in controlling the velocities or the flow pattern of a fluid (Bill Rehm, 2009), (Overmeen, 2020). The three different categories that Reynolds number puts fluid systems in are laminar, transitional, and turbulent flow (Struck, 2015).

THE IMPORTANCE OF REYNOLDS NUMBER

Reynolds number plays a major role and is important when testing a scale model, this is because the scaled models Reynolds number should be the same as the model on a larger scale. Therefore, we can predict the type of fluid flow on a real full-scale model. It is also important to know the Reynolds number in general, so that we can see if the flow is laminar or turbulent as if the flow is turbulent then there is increased mixing and shearing (Menon, 2015). By this happening there is an increased number of viscous losses which can affect the efficiency of machines and systems (OCW, 2003).

REYNOLDS NUMBER CALCULATION FORMULA

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

μ – fluid dynamic viscosity in kg/(m.s)

ρ – fluid density in kg/m³

V – fluid velocity in m/s

D – pipe diameter in m

FIGURE 2. REYNOLDS NUMBER EQUATION (NCALCULATORS, 2016).

LAMINAR, TRANSITIONAL AND TURBULENT FLOW

If Reynolds number is below 2100, usually, they have laminar flow, if Reynolds number is larger than 4000 then it is typically turbulent flow and if it is between 2100–4000 the flow is known as transitional (Menon, 2015), (Bruce R. Munson, et al., 2013). With laminar flow, the fluid is orderly with all particles moving parallel to the pipe's boundaries, with them moving in a smooth path and the particles not interfering with one another. When there is laminar flow, this also means that the velocity is constant at any point in the fluid. Turbulent flow is then the opposite of laminar flow where the particles flow irregular causing swirls in the fluid, and the velocity of the fluid doesn't remain constant throughout (Mishra, 2016). In figure 3 below it shows the ranges and different types of flow.

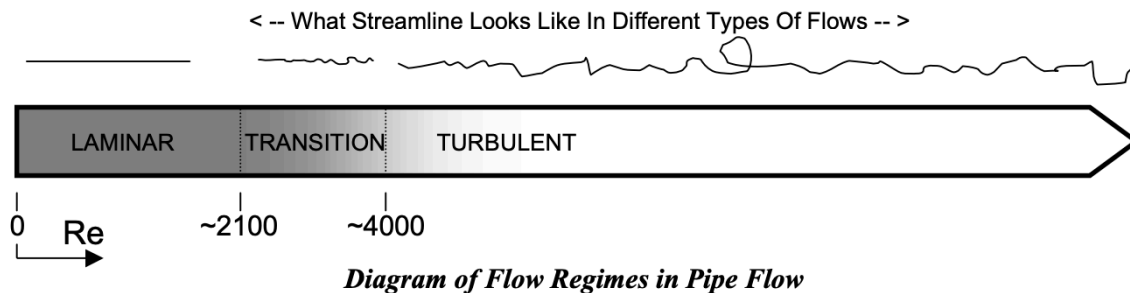


FIGURE 3 REPRESENTATION AND RANGES OF THE DIFFERENT TYPES OF FLOW (OCW, 2003).

ESTIMATED REYNOLDS NUMBER OF THE FLUID FLOWING AROUND THE BUTTERFLY VALVE

I have estimated that the Reynolds number in this butterfly valve system would be greater than 4000 when the petroleum fluid hits the butterfly valve and flows through, only if the valve is partially open. I think this even though the flow is laminar and flowing parallel before the butterfly valve, the plate in the valve at an angle would disrupt the flow of the petroleum. Therefore, I think the fluid flow would be turbulent at the butterfly valve and after it passes through it. However, if the butterfly valve is fully open, at 90° I believe the flow would remain laminar as there isn't much surface area on the disc effecting the flow, so the flow would remain flowing relatively parallel.

TASK 2

BOUNDARY FLOW AROUND THE BUTTERFLY VALVE

The boundary flow around the valve would be turbulent when the disc is partially opened, this is due to the butterfly valves plate affecting the flow of the petroleum and causing swirls around and just after the valve. When the butterfly's disc is fully open, so at 90 degrees, I think the flow around the butterfly valve will stay laminar as the surface area of the disc is reduced very small, and the fluid should still be flowing in a relatively straight line with no vortexes/swirls occurring. The separation around the valve changes depending on the angle the disk is at in the valve, the smaller the angle (so when the valve is closed more) there will be greater separation with the fluid having only small gaps to flow through at the top and bottom of the disc. The rivets that hold the valve onto the central shaft can also affect the flow of the fluid due to the disc not having a smooth surface area, but the effect of the rivets on the flow would probably be very minimal.

WHY HAS THE BUTTERFLY VALVE BEEN DESIGNED LIKE THIS?

I think that the valve has been designed like this with rivets holding the disc onto the central shaft because possibly the machinery/technology wasn't available such as 3D printing to make the shaft and disc as one, rather than two separate parts joined together. The design used is a relatively simplistic design compared to most on the market. Another alternative to using rivets would have been bolts, but I think rivets would have been used instead of bolts and nuts as the rivets create a better seal compared to bolts, therefore the fluid would be less likely pass through when the disc/valve is closed. Rivets also may have been chosen over bolts as the rivets head had a smaller surface area when compared to bolts so would have less of an effect on the fluid flow. A final reason I think potentially rivets were used to hold the disc to the central shaft is that the disc is the component in the butterfly valve which has the most wear. So therefore, if the disc needs replacing due to wear or cracks forming on the disc overtime it can be. This would be done by drilling out the rivets, drilling new holes in a new disc and riveting the new disc to the central shaft.

HISTORICAL TESTING OF GRP BUTTERFLY VALVES

Historically looking at GRP valves there isn't much record of them being used but I have found that one company decided to test them back in 1980. The company was Fawley power station which is a seaside power station. They decided to test GRP butterfly valves due to their current cast iron butterfly valves suffering from corrosion due to being exposed to the harsh conditions of the seaside (M. H. Bryan-Brown & Walker, 1983).

COST IMPLICATIONS OF THE BUTTERFLY VALVE DESIGN

The cost implications of the butterfly valve being designed like it has been with the rivets holding the disc to the central shaft, are firstly, the rivets cannot be replaced easily once installed and they may need replacing often depending on the amount of use and operating conditions. To remove the rivets and install new ones the old rivets will have to be carefully drilled out without making the hole bigger and then new rivets installed. This would potentially cost you financially mainly due to the fact the system would have to be shut off, the valve disconnected and taken apart, so that the rivets can be replaced. By using rivets to hold the disc to the shaft, overtime the rivets could become loose, causing potential for leaking. This may have cost implications due to the potential waste of petroleum there will be if it is leaking when the valve is shut off.

Lastly, by the butterfly valve being designed with no seal or seat around the disc or body of the butterfly valve it could again mean that when the valve/disc is closed fully some fluid may still leaked through. The seat in a butterfly valve would utilise an interference fit between the discs edge and the seat itself to create a better seal and provide a complete shut off in the butterfly valve (Moore, 2016).

TASK 3

IMPLICATIONS OF THE BUTTERFLY VALVE BEING MANUFACTURED FROM GRP

The butterfly valve being manufactured from glass fibre reinforced plastic (GRP) brings many advantages such as its low-cost relative to other materials, but there are also a few implications. Even though glass fibre reinforced plastic has high strength, is lightweight and is corrosion resistant in many environments, at high temperatures the materials strength decreases (Higgins, 1994). When the strength is decreased it would increase the amount of deflection on the valve as well, due to its poor stiffness and rigidity it wouldn't return to its original form either. Under heavy and sustained loads, it will continue deflecting the valve as well and this could potentially cause it to crack and potentially fail over time. (James Groenier, et al., 2006).

Another downside of the butterfly valve being manufactured from GRP is even though they it has a higher stiffness than most plastics, its stiffness is much less than that of mild steel. However good quality GRP products should remain structurally sound for at least 30 years. By using GRP if you get any exposure to the fibres, they can slowly breakdown the fibres bond with the resin. If any of the GRP butterfly valves surface gets scratched or damaged, it will be difficult to repair so this may mean a whole new butterfly valve may be needed. A major implication of using GRP for the butterfly valve is that unpigmented products have high light transmission of up too 70%, but greater products like self-extinguishing grades still suffer major loss of transparency and colours exposed to weather conditions can fade within 5 years (Riba, 1994). This is a major issue because if the GRP material allows light transmission, the GRP butterfly valve in the system has petroleum flowing through the valve which is a highly flammable fluid, and the butterfly valve is exposed to the sun it could potentially ignite the petroleum causing a fire/explosion.

STANDARDS WHEN MANUFACTURING THE BUTTERFLY VALVE

When manufacturing the butterfly valve that is going to be inserted into a pipeline to form the outlet at the base of a 5m high storage tank, it will be required to meet industry and British standards. One standard which must be adhered to that is related to the use of GRP in pipes and fittings is the BS 5480 (Riba, 1994). There are also standards which relate specifically to the GRP material used to ensure it is up manufactured to British standards. The standards are BS 3496, BS 3691 and BS 3749 (Riba, 1994).

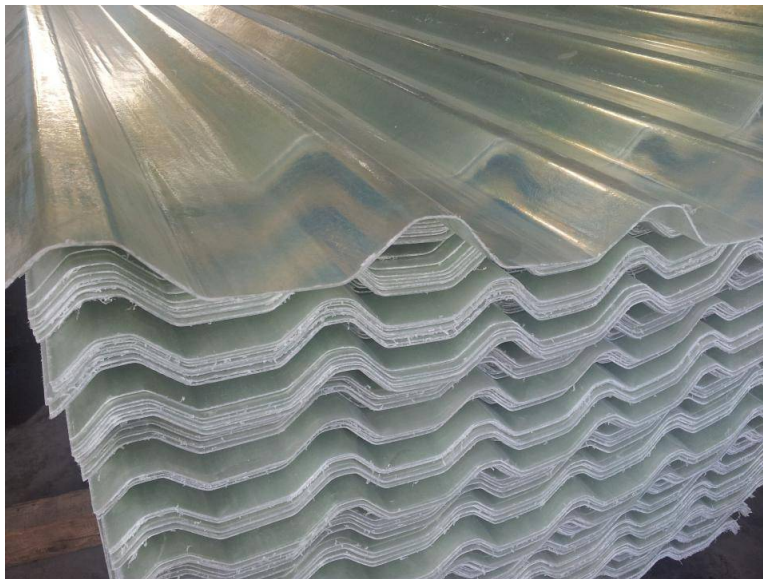


FIGURE 4. TRANSPARENT GRP USED FOR ROOFING SHEETS (ECPLAZA, 2021)

TASK 4

MODELLING TECHNIQUES TO SIMULATE FLUID FLOW

Modelling techniques can be used to simulate what the fluid flow would be like through the butterfly valve with the different techniques having certain pros and cons. One modelling technique which could be used is computational fluid dynamics (CFD) software, this allows you to create a 3D model of your entire system, on your computer, and run a simulation to see what the real fluid flow/performance would be like. Another modelling technique which can be used is to create a physical model/prototype of the system but scaled down to a smaller size and carry out experiments/tests on it to gather data and to see if it would function as required.

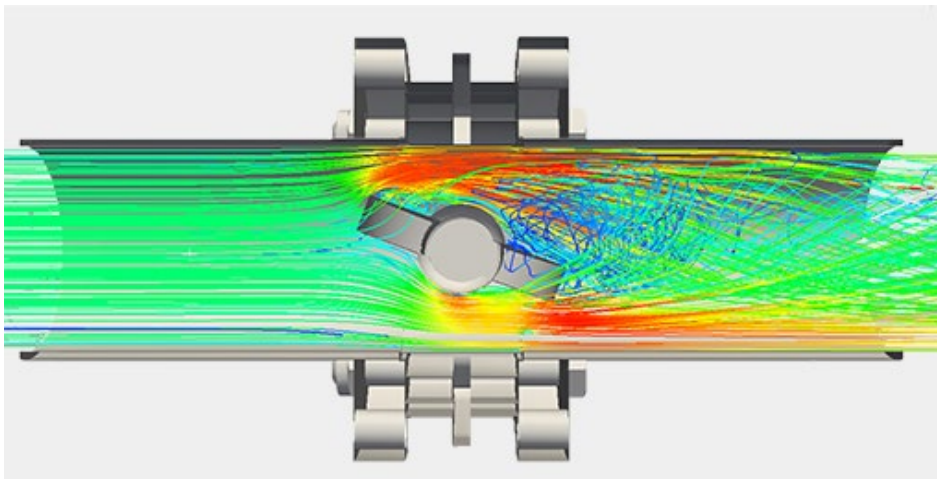


FIGURE 5. CFD SIMULATION ON A BUTTERFLY VALVE (SCALE, 2015)

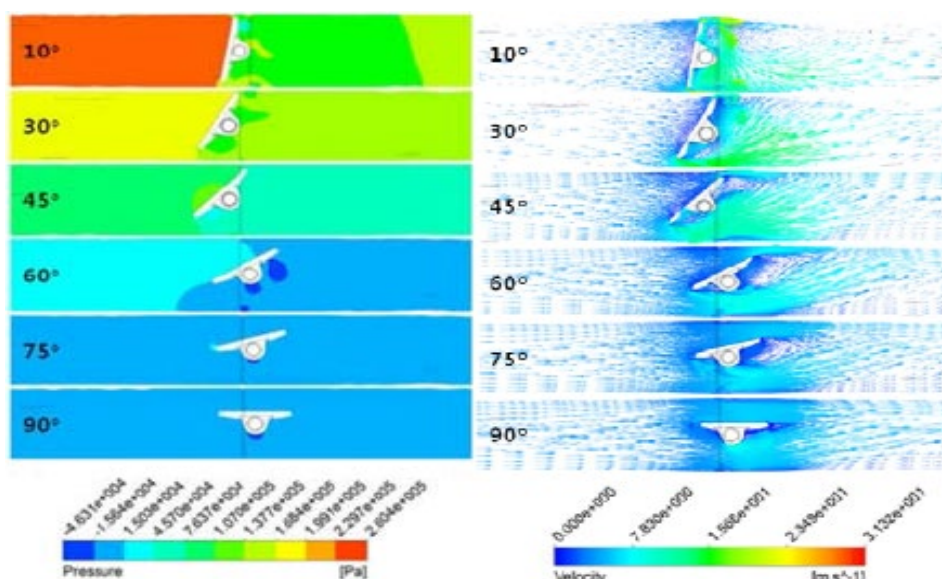


FIGURE 6. SIMULATION CARRIED OUT WITH THE BUTTERFLY VALVES DISC AT DIFFERENT ANGLES (JUN TAE AHN, ET AL., SEPTEMBER 2011).

CFD ADVANTAGES

An advantage of CFD is that it could be used to investigate failure of old infrastructure after the event to give engineers a relatively accurate picture/ greater understanding of what happened and why the failure occurred. (Team, 2019). CFD also gives you the ability to gather measured data at any point in the pipe/valve and you can gather many flow parameters which you can't discover in experiments (Ifes, n.d.). The costs associated with CFD can be lower compared to experiments, they are generally 20-40% less than a physical model, but it all depends on how well trained you are at using the CFD software. (Linfield & Mudry., 2008). As if you need to pay someone more qualified than you to carry out the simulation for you and the cost and time of manufacturing a prototype is low then the labour costs for the CFD simulation could be greater than creating a prototype/scaled model. By carrying out CFD you can see the performance of the system before fabricating it, so you can forecast what changes in the design are needed and which are the most crucial to improve the performance (Patel, 2013).

CFD DISADVANTAGES

A disadvantage of CFD software is that for complex and large models it can take long work hours to complete them ready for simulation. Errors may also occur in CFD simulations due to simple flow models or simplified boundary conditions. When looking at CFD it all depends on how good and well the user knows the software, as to be able to carry out simulations accurately on it they will need to be very experienced with the programme (Munson, et al., 2013). Otherwise, the results could be inaccurate, if errors are made and without expertise in CFD software it could take more work hours to create than a fabricated model. Other problems that may arise with CFD is you may have difficulties dealing with non-linear terms of the Navier-Stokes equation, difficulties in modelling turbulent flow systems and possible convergence issues (Munson, et al., 2013). A final limitation of CFD is that the model created on the software can only be as accurate as the physical model and the solution is only accurate as the boundary conditions provided.

SCALED DOWN PROTOTYPE MODEL ADVANTAGES

When looking at the prospect of fabricating a scaled down prototype model of the system to simulate the fluid flow through the valve there will be benefits of doing this but also disadvantages when compared to other modelling techniques like CFD. Advantages of making a scaled down model of the system is that it helps you, your team or customers get a clear picture of what is expected, and it clears up any miscommunications or misunderstandings they may be between one another when still early in the process. By clearing up any issues or misunderstandings early on it can save a lot financially as a scaled down model will cost less and take less time to fabricate compared to the real-life sized system. If you already have the practical skills to fabricate the system with the valve, then no more specialised training is required to produce a scaled model. Unlike with CFD you need to be trained how to use the software by an expert especially before carrying out simulations on complex models (Linfield & Mudry., 2008).

SCALED DOWN PROTOTYPE MODEL DISADVANTAGES

Now I will be looking at the disadvantages of a scaled down fabricated prototype model, the same as all things there are downsides that come along with the benefits. A disadvantage of using a prototype as a modelling technique is that it can be more costly than using CFD software to carry out the simulation, as if you don't have the tools or materials readily available and must go out and purchase them all, depending on the tools and materials required the cost could be a lot more. Fabricating a prototype model is also more labour intensive compared to using CFD software and depending on how complex the system/product is will take a lot longer to produce, compared to on CFD software. When fabricating a prototype model if mistakes are made such as cutting a part to the wrong size, shape or if a hole is drilled in the wrong place, then it might mean you have to start fabricating the model from the start again. As if too much is cut off a certain section it can't be undone, unlike on CFD software there is the option to undo your last action to rectify it easily.

TASK 5

EXPERIMENT TO COMPARE TO THE SIMULATION

During the development of the butterfly valve component, it is proposed that a prototype is produced and tested in a laboratory, so the fluid flow through the valve can be understood and correlated to a simulation carried out. For this task I will be explaining and discussing how I would go about the experiment and retrieve the data required.

EXPERIMENT PROCEDURE

The experiment steps I would carry out to be able to correlate the results of the laboratory to the CFD simulation are as follows:

1. Fabricate a prototype of the butterfly valve out of transparent GRP but scaled down ten times smaller using a ratio of 10:1.
2. Fabricate the pipeline, petroleum storage tank and whole system. The pipeline being made from transparent GRP.
3. Once all components and parts are fabricated and the system has been put together add petroleum to the scaled down petroleum storage tank which will now be 0.5m high, ensuring the butterfly valve is closed.
4. Set up a camera to then record and focus on the butterfly valve ready to monitor the flow of the petroleum through the valve.
5. Gather a dye suitable for the petroleum which will show the fluid flow characteristics of the petroleum.
6. Firstly, open the butterfly valve disc to 10° and when doing so ensure the camera is recording the fluid flow and add the dye which will then shows the flow patterns.
7. Next the butterfly valves disc should then be set to 30°, 50°, 70° and finally 90° (fully open).
8. Each time the valve is opened more ensure that there is enough dye added so the fluid flow can be seen clearly.
9. Once all data has been recorded at each angle stop the recording and shut off the butterfly valve to stop the fluid flow.
10. Now the laboratory is complete you will be able to analyse the recordings of the fluid flow at each angle and correlate the type of flow at each point, with the computer-generated simulation results.

EXPERIMENT DISCUSSION

To carry out the laboratory the prototype will need to be fabricated accurately so it operates the same as the final product will. For the prototype in this laboratory however, I decided I would scale everything down using the ratio 10:1. I decided this as you would save costs on materials, potentially save time on labour fabricating it and by making the prototype and whole system 10 times smaller it means that the experiment can easily be carried out in a laboratory. As if the system and prototype was fabricated to scale, the 5-metre-high tank for the petroleum may not fit in most laboratory's or would take up a lot of space.

The pipeline and butterfly valve for this laboratory also is needed to be made from transparent GRP, this is so the fluid flow can be seen when flowing through the valve. I think when observing the fluid flow, you should find that as the angle of the disc in the valve increases the turbulence at the butterfly valve will decrease. This result should then correlate and be like the simulation carried out on the computer. I chose to also use a camera in the experiment to record the fluid flow as this would allow everyone to look back at the footage at what happened with the fluid flow at the butterfly valve, so it could be analysed more and compared side by side with the simulation results.

CONCLUSION

To end my report, I will conclude my findings, discuss how I felt it has gone and mention any difficulties I had throughout.

I have discussed and explained several topics around fluid flow, the butterfly valve, modelling techniques and stated advantages and disadvantages of decisions made. When carrying out the tasks set out, I did find it difficult to retrieve data and information on GRP butterfly valves specifically. I think this was because they aren't commonly manufactured or used much, as there are a few better alternatives available on the market that are probably better suited to the tasks the butterfly valves are used for. From carrying out research between CFD and prototype modelling techniques I think that CFD in general would be the best technique to pick if you are familiar and know how to use the software. Even though there have been a few difficulties throughout this assignment report I do feel I have consolidated and built upon what has been discussed during my lectures.

BIBLIOGRAPHY

- Bill Rehm, J. S. A. H. A. S. P. J. H., 2009. *Managed Pressure Drilling*. 1st ed. Houston, Texas: Gulf Publishing Company.
- Bruce R. Munson, Theodore H. Okiishi, Wade W. Huebsch & Rothmayer, A. P., 2013. Transition from Laminar to Turbulent Flow. In: *Fluid Mechanics Seventh Edition*. Hoboken, New Jersey: John Wiley & Sons Singapore Pte. Ltd., p. 414.
- Ecplaza, 2021. *Ecplaza*. [Online]
Available at: https://www.ecplaza.net/products/glass-fibre-reinforced-plastic-sheets_4039525
[Accessed 28th July 2021].
- Higgins, R. A., 1994. *Properties of Engineering Materials Second Edition*. Second Edition ed. London : St Edmundsbury Press Ltd .
- Ifes, n.d. *ifes koeln*. [Online]
Available at: <https://www.ifes-koeln.de/en/services-20-years-project-experience/simulation-analysis/computational-fluid-dynamics-cfd.html>
[Accessed 22nd July 2021].
- James Groenier, Merv Eriksson & Kosmalski, S., 2006. *T&D Publications*. [Online]
Available at: <https://www.fs.fed.us/t-d/pubs/htmlpubs/htm06232824/page03.htm>
[Accessed 21st July 2021].
- Jun Tae Ahn, Kyung Chul Lee, Kwon Hee Lee & Han, S.-H., September 2011. Investigation of the mechanical behavior of a flexible solid metal seal for a cryogenic butterfly valve. *Journal of mechanical science and Technology*, 25(9), pp. 2393-2400.
- Khan, I. A., 1987. Dimensional Analysis . In: J. J. Beck, ed. *Fluid Mechanics*. United States of America : Ted Buchholz, p. 225.
- Linfield, K. W. & Mudry., R. G., 2008. *Pros and Cons of CFD and Physical Flow Modeling*. [Online]
Available at: <https://docplayer.net/19828385-Pros-and-cons-of-cfd-and-physical-flow-modeling-a-white-paper-by-kevin-w-linfield-ph-d-p-e-robert-g-mudry-p-e.html>
[Accessed 22nd July 2021].
- M. H. Bryan-Brown & Walker, D. M., 1983. Large GRP Butterfly Valves . In: I. H. Marshall, ed. *Composite Structures 2*. Bristol, England : Applied Science Publishers Ltd, pp. 214-234.
- Menon, E. S., 2015. Liquid: Reynolds number . In: E. S. Menon, ed. *Transmission pipeline calculations and simulations manual*. s.l.:Gulf professional publishing , pp. 149-234.
- Menon, E. S., 2015. *Transmission pipeline calculations and simulations manual*. First ed. Arizona, USA : Gulf professional publishing .
- Mishra, P., 2016. *Difference between Laminar and Turbulent flow*. [Online]
Available at: www.mechanicalbooster.com
[Accessed 24th July 2021].
- Moore, R., 2016. *Butterfly Valve Basics*. [Online]
Available at: <https://www.controleng.com/articles/butterfly-valve-basics/>
[Accessed 24th July 2021].
- Munson, B. R., Okiishi, T. H., Huebsch, W. W. & P.Rothmayer, A., 2013. Difficulties in CFD. In: *Fluid Mechanics 7th Edition*. Hoboken, New Jersey: John Wiley & Sons Singapore Pte. Ltd., p. 732.
- Munson, B. R., Okiishi, T. H., Huebsch, W. W. & Rothmayer, A. P., 2013. Advantages of CFD. In: *Fluid Mechanics 7th Edition*. seventh ed. Hoboken, New Jersey: John Wiley & Sons Singapore Pte. Ltd., p. 732.

- ncalculators, 2016. *Reynolds number formula*. [Online]
Available at: <https://ncalculators.com/mechanical/reynolds-number-calculator.htm>
[Accessed 23rd July 2021].
- OCW, 2003. *Turbulent Flow, Reynolds Number & Pipe Flow*. [Online]
Available at: <https://ocw.mit.edu/courses/mechanical-engineering/2-000-how-and-why-machines-work-spring-2002/study-materials/TurbulentFlow.pdf>
[Accessed 25th July 2021].
- Overmeen, A., 2020. *What is the difference between laminar and turbulent flow?*. [Online]
Available at: <https://www.bronkhorst.com/en-gb/blog/what-is-the-difference-between-laminar-flow-and-turbulent-flow-en/>
[Accessed 23rd July 2021].
- Patel, M., 2013. *Hitech CFD*. [Online]
Available at: <https://www.hitechcf.com/cfd-knowledgebase/cfd-simulation-benefits-practical-applications.html>
[Accessed 23rd July 2021].
- Riba, A. E., 1994. Glass . In: L. g. U. limited, ed. *Materials Fifth edition* . Great Britian : B T Batsford Ltd, p. 208.
- Riba, A. E., 1994. Plastic and rubbers . In: L. g. U. limited, ed. *Materials Fifth edition* . Great Britian : B T Batsford Ltd., p. 225.
- Riba, A. E., 1994. Plastics and rubbers . In: L. G. U. Limited, ed. *Materials Fifth edition* . Great Britian : B T Batsford Ltd. , p. 225.
- Scale, S., 2015. *Sim Scale*. [Online]
Available at: <https://www.simscale.com/valves-simulation/>
[Accessed 24th July 2021].
- Struck, S., 2015. *Science Struck*. [Online]
Available at: <https://sciencestruck.com/what-is-reynolds-number-what-are-its-applications>
[Accessed 22nd July 2021].
- Team, S., 2019. *13 Key Applications of CFD Simulation and Modeling*. [Online]
Available at: <https://blog.spatial.com/cfd-modeling-applications>
[Accessed 21st July 2021].