



Universidad de Valladolid



**ESCUELA DE INGENIERÍAS
INDUSTRIALES**

UNIVERSIDAD DE VALLADOLID

ESCUELA DE INGENIERIAS INDUSTRIALES

Grado en Ingeniería Mecánica

Diseño de una Válvula de Bypass

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TFG REALIZADO EN PROGRAMA DE INTERCAMBIO

TÍTULO: **Design of Bypass valve**

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RESUMEN EN CASTELLANO

Noruega recibe casi toda su energía eléctrica (96%) de plantas hidroeléctricas. Esto supone que la única vía de salida del agua de la presa sea a través de la turbina. Teniendo en cuenta que la turbina en algún momento ha de parar, por fallo o mantenimiento, el río aguas abajo se quedará sin agua, infligiendo un gran daño a la biodiversidad del mismo.

Para evitarlo, se instala un sistema de bypass como ruta alternativa. Estos sistemas deben cumplir dos requisitos principales: controlar el caudal y disipar la energía que en su caso se transformaría en la turbina, para evitar daños por altas velocidades.

Este proyecto, propuesto por la empresa Multiconsult, consiste en crear una válvula que soporte hasta 300 m.c.a., minimice el daño producido por la cavitación, y utilice procesos de fabricación de bajo coste y que permitan realizar modificaciones para adaptar cada válvula a cada cliente.

PALABRAS CLAVE

- Diseño incremental
- Mecánica de Fluidos
- Válvula
- Método de Elementos Finitos
- Análisis de Riesgos

Sensur av hovedoppgaver

Universitetet i Sørøst-Norge

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Design of bypass valve

Design av forblislippingsventil

Utført i samarbeid med: Multiconsult Norge AS

Ekstern veileder: Bjarne Børresen

Sammendrag: For å sikre vann nedstrøms i et vannkraftverk installeres ofte et forblislippingsanlegg. Et slikt anlegg har en forblislippingsventil som har i oppgave å regulere vannstrømmen og dissipere energi. Oppgaven er å utvikle et parametrisk design av en slik ventil.

Stikkord:

- Design
- Fluidmekanikk
- Ventil

Tilgjengelig: JA

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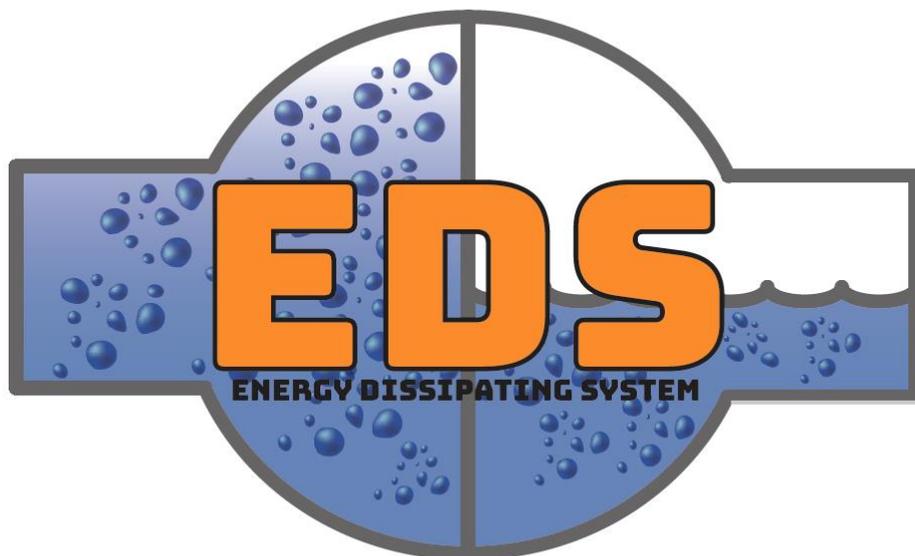
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Design of bypass valve

Bachelor thesis

22.05.2018



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Executive summary

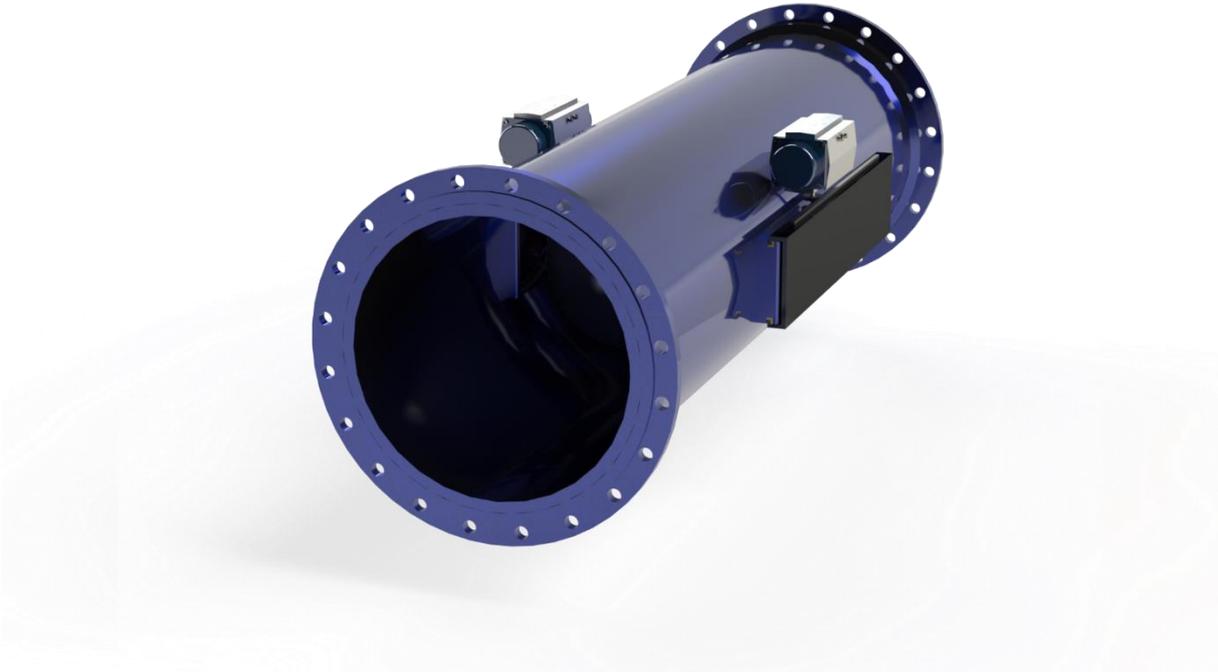
Mountains, rivers, and waterfalls in Norway provide optimal conditions for hydropower plants. The most efficient way to use hydropower is to build dams or use natural reservoirs to control the flow of water and electricity production. The only way for the water to continue downstream in the river is now through the turbine. If the turbine stops, either due to a critical failure or due to a power outage at the station, it will cause a considerable risk to the biological diversity downstream in the river. Infant fish can die after just minutes without flowing water. The solution to this problem is to install a bypass facility. When the turbine stops, the facility redirects the flow to bypass the turbine so that the river downstream still has flowing water. The hydropower bypass solutions that are available today are optimized for larger sized power plants which may decrease the profit-margin for smaller sized plants.

This bachelor thesis describes and evaluates different hydropower bypass solutions for medium to smaller sized power plants. It is based on a task formulated by Multiconsult. This task is to design and parametrize an alternative valve or energy dissipater that should cost less than the current available alternatives.

Ten concepts were developed that could fulfill the requirements, and through the use of a Pugh-matrix and criterion analysis the Energy Dissipating System (EDS) was chosen to be the best. It is designed to deal with cavitation so that essential parts of the valve are not damaged. Flow and FEM simulations also suggest that EDS will fulfill the flow and material requirements set by the Norwegian Water Resources and Energy Directorate (NVE). The current valve alternatives are produced by casting the valve body which can be a time-consuming and a costly process, especially if the product is not mass produced. Since EDS will not be mass-produced, the system was designed to be produced with alternative methods, such as plate rolling and cutting. These methods are assumed to decrease the cost of smaller production quantities. With more optimization of the design and production methods, the group is confident that EDS can be a cost-efficient alternative to bypass valves used in the industry today.



Energy dissipating system



Introduction

The task specified from Multiconsult was to design and parametrize an alternative bypass valve. The first chapter contains an overview of the project model and how the work was structured from the start. The second chapter contains the concept analysis and the selection of the final concept. Chapters 3 to 7 are about the design and optimization of the Energy Dissipating System (EDS). Chapter 8 describes the test that was done and how EDS performed within each of them. The two last chapters are a conclusion for our project and an evaluation, both as a group and individual.



Acknowledgements

Many contributed greatly to this bachelor thesis. The group would like to extend gratitude to the following people for their support and guidance.

Karoline Moholth as internal sensor

Ingerid Fossum as internal supervisor

Bjarne Børresen as external sensor and supervisor

Mattias Kullberg as external supervisor



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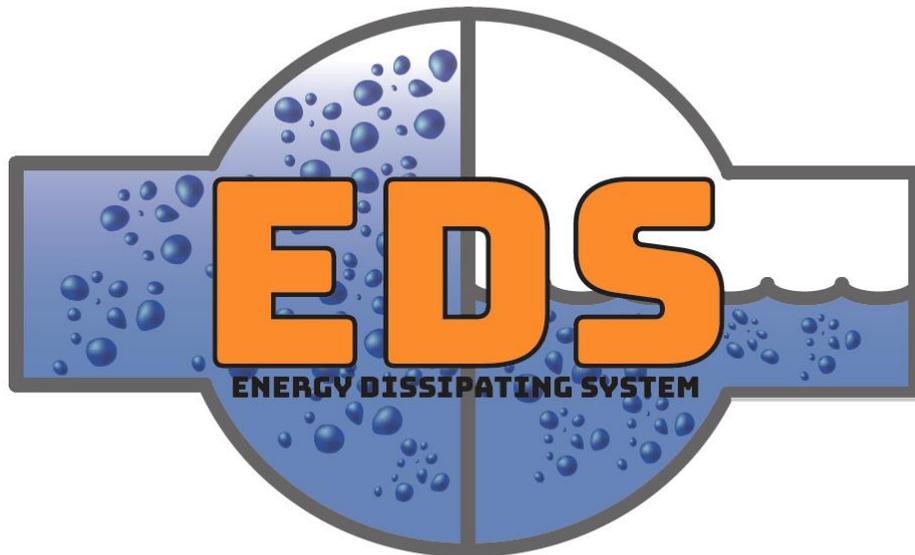
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Multiconsult

Design of bypass valve Project Plan

22.05.2018



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1 Introduction

1.1 The group

Our project group consists of four members, all of which is studying mechanical engineering. Three who study at HSN Kongsberg and one who studies at University of Valladolid, Spain. The bachelor thesis is the students chance to get more practical experience within the theoretical subjects.

All the group members are studying mechanical engineering, and this will influence the activities we perform.

1.2 Project description

Norway is one of the only countries that receive close to all its energy from renewable energy sources at around 98% (International Energy Agency, 2017, p. 127). Hydropower has supplied more or less all the required electricity in Norway, where as its current share is around 96%. The most efficient way to use hydropower is to build dams or use natural reservoirs to control the water flow and electricity production better. This result in that the only way for the water to continue downstream is through the turbine. If this turbine were to stop, the water flow in the river would stop and cause the biological diversity downstream to suffer severely or in the worst-case die.

To stop this from happening, bypass systems are installed. These are systems that allow the water to flow a route around the turbine, and continue its journey downstream. An important aspect of a bypass system is to slow the water down, to not cause any harm to the power plant and the immediate surroundings downstream. A general rule is that 50% of the water that would have hit the turbine at maximum capacity should continue downstream.

Within this bypass system, there is a valve. This valve controls the water flow rate. The valve is either used as a standalone valve, or in conjunction with an energy-dissipater. This combination causes only a certain amount of water to be let through, and at a certain speed.

The problem with this solution is that it is complex and expensive to produce, making it an unviable option for many power plants and hits smaller power plants the hardest, creating the question if a bypass-facility really is necessary.

Our project, presented by Multiconsult, will be to design an alternative valve or energy-dissipater. The product should come in at a lower price than existing alternatives, is reliable, scalable, be easy to maintain, and be remotely controlled.

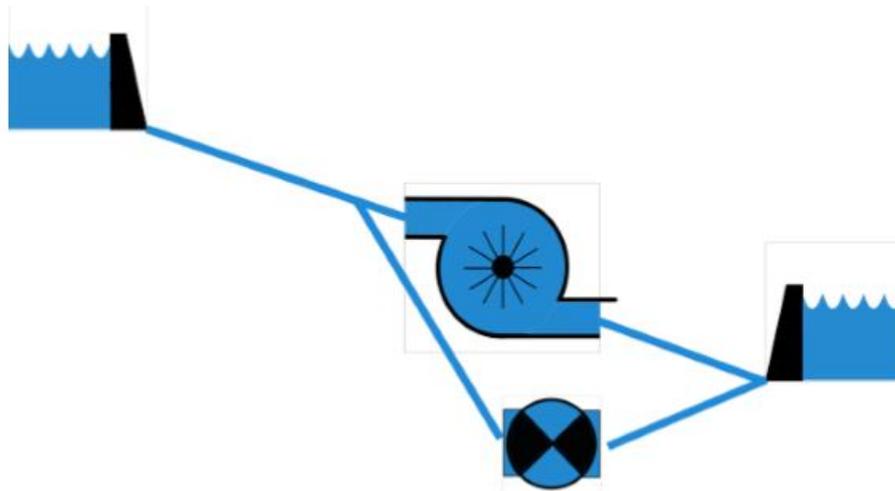


Figure 1: Hydropower plant with a bypass facility

1.3 Scope

The bachelor thesis's duration is one semester, and the assignment and expectations must be tuned to fit this timeframe. Multiconsult expects a parametrized model of a new type of bypass valve. This includes but is not limited to:

- A CAD-model of the valve
- Flow-, material- and cost/benefit analysis's
- Production method
- The valve should be scalable to increase the usability

If time allows it, a prototype can be made. This is not a requirement and merely seen as a bonus.

1.4 Expectations

Although the project is of substantial size with assistance from Multiconsult and USN, we are confident that we will accomplish the task at hand. The group has several expectations going into the project, here are some of them:

- To develop a parametric design of a product that satisfies the stakeholders.
- Getting more experience with working on a long-term project and in project planning
- Develop a good group dynamic.
- Operate professionally throughout the project.
- Acquire knowledge within multiple disciplines.
- Get more experienced in engineering, both practically and theoretically.

2 Project organization

2.1 Project members

Oskar Oulie



Born and raised on a farm in Steinberg. One of my hobbies is working on the farm. This can involve everything from maintenance of machinery to animal husbandry. Served in the Norwegian army in the period 2014-2015. Currently studying mechanical engineering at HSN Kongsberg.

Markus Hjellseth



Born in Arendal, but raised in Slemmestad, Røyken. Already hold a bachelor in Product Design from HiOA, class of 2015. At HiOA I learned a lot about design, what makes a design good or bad, and different design-techniques, as well as project management. My hobbies include training, golf, being active outside and carpentry, but the biggest one is paintball. In the 8 years I've played paintball, I've earned multiple national and international medals, topping it off with a 2nd place from World Cup 2016 with the national team. I feel that my paintball career is really something that has helped me become a team-player and work well in groups. I'm currently living in Kongsberg where I study mechanical engineering / Product Development at HSN Kongsberg.

Lars Berg Røste Hvidsten

Born and raised in Bærum, Akershus. My hobbies are skiing, hiking and swimming. I served in the Norwegian Army as a border patrol in Kirkenes from 2013 to 2014. After that I started at UiA Grimstad as a software engineer, but quickly realized that my interest was more in the mechanical field. After completing the first year in Grimstad I changed to HSN Kongsberg where I currently study mechanical engineering/ product development. I currently live with my wife in Kongsberg.

José Mato Sanz

Born and raised in Tudela de Duero, Valladolid, Spain. As a hobby, I like playing the guitar or the electric bass. I am a senior mechanical engineering student in a four-year degree in Valladolid. Last summer, I did an internship in a development end investigation company in the field of cars safety.

2.2 Roles and responsibilities

Project leader (Oskar Oulie)

The project leader should at all time have an overview of the project, delegation of tasks, as well as an overview of progression and presence of group members. The project leader will also act as a contact person between the internal and external supervisors.

Requirements manager (Lars Bergh Røste Hvidsten)

The Requirement manager oversees the requirements specification and makes sure it's updated. He also needs to have an open dialogue with Multiconsult regarding the requirements.

Test manager (José Mato Sanz)

The test manager responsibility is to keep the test plan updated and that the tests are in accordance with the project plan and test specification. The test manager will also oversee the tests and make sure they are carried out in compliance with the specification and the validity of each test.

Risk manager (Markus Hjellseth)

The risk manager is responsible for creating a risk analysis for the project. One of the key focuses within the unified process is to understand the risks that may affect the system. This will mitigate the risk for the project to fail.

Budget manager

~~The budget manager is responsible for monitoring the product costs. The primary focus here is the fabrication, and to find the best and cheapest ways to produce the product.~~

The budget manager was later changed to production manager (for explanation look at the evaluation see Project conclusion & Project evaluation).

Website manager (Lars Bergh Røste Hvidsten)

The website manager is responsible for making a website and keeping this site updated. The website should contain information about the group, the project, and the progress.

Chief of Flow analysis (Oskar Oulie)

Here, the main responsibility is to make sure that the flow analysis is done correctly and is as realistic as possible. Flow analysis a sub-program of Solidworks, meaning that the CAD-model designed in Solidworks will be used to do the flow analysis.

Head of Final Element Method (FEM) (Lars Berg Røste Hvidsten)

The Head of FEM is responsible for the FEM analyses that will be done to the model. It is important to get a good understanding of FEM to ensure good analyses.

Designer/CAD-manager (Markus Hjellseth)

The main responsibility for the Designer/CAD-manager will be to construct the product in SolidWorks. This model will be used for display, various testing and possibly 3D-printing. It is therefore prominent that the model is of high quality.

2.3 Stakeholders

A stakeholder is someone, a group, or an association that is impacted by something. For this project, that means everyone, and everything affected by the system or the water running through it. There are two types of stakeholders, active and passive.

A system is defined as “a collection of hardware, software, people, facilities and procedures organized to accomplish some common objective” (Buede, 2009, p. 3). The stakeholders for the system are those who hold these objectives.

Who	Description	Active/passive	Consideration
Multiconsult	Customer	Active	Meet customer requirements. Provide a system that delivers the expectations
HSN	Internal supervisor and Internal sensor	Active	Meet requirements and expectations for the project. Keep deadlines, presentations, meetings and project model.
Norwegian government	NVE	Passive	Create a system which remains within the requirements set in “damsikkerhetsforskriften”
Local environment	Living organisms	Passive	Create an environmentally friendly system that does not harm the environment.
Hydropower plant	Owners and users	Passive	Create a system that is maintenance-friendly and economically beneficial. Make the system user-friendly according to HMS.

Table 1: Stakeholders

2.4 Multiconsult

The project handed to the group is given by one of the leading engineering- and consulting companies in Norway, Multiconsult. The company roots back to the early 1900's, more specifically 1908, and has had a significant impact on Norway's development ever since, both engineering wise and financially. Multiconsult provides a variety of services, including engineering, consulting, architecture, leadership, verification and management. All who are offered both nationally and internationally. Multiconsult holds engineering offices in Ethiopia and Nepal, sales offices in the Philippines and Kenya, along with a series of partners in Africa, Asia, Europe, the middle east, and North-America.

The list of achievements and projects that Multiconsult has been a part of is long, but these are some of them:

- Participated in national and international development of hydroelectric power plants for over a century.
- Been a part of the Norwegian oil-adventure since the 70's.
- Helped develop a high-speed railroad in South-East Norway and continue to contribute to projects for Jernbaneverket.
- Contributed to the development of Holmenkollen, the Olympic arena in 1952.
- Been a central part in the development of Bjørvika, through projects in Barcode, the Munch museum and the Deichmanske Library.
- Been a part of major projects for Statens vegvesen.

2.5 Accountable

2.5.1 Multiconsult

Multiconsult AS

Strømsø Torg 9, 3044 Drammen

External consultant/sensor (Bjarne Børresen)

Stepping into the role as the group's external sensor and supervisor is Bjarne Børresen. He is the leader of energy and machine department at Multiconsult, Drammen. This means that he will be our primary contact at Multiconsult, and he and his team will guide us if necessary.

Having a consultant at Multiconsult is crucial as he holds the information to make this project a success. We will use his guidance throughout the project, and continuously have contact with him through mail, meetings and other media.

It is expected that the external supervisor is present during all three presentations. As he is also our external sensor, he will be a part of the sensor team that will grade the group's final paper.

2.5.2 ^{HSN} Universitet i South-Eastern Norway

Hasbergs vei 36, 3616 Kongsberg

Internal sensor (Karoline Moholt McClenaghan)

Internal sensor is Karoline Moholt McClenaghan. She oversees the sensing process, the grading of each group, as well as having the main responsibility for all the bachelor groups. Internal sensor must be present during all three presentations.

Internal supervisor (Ingerid Fossum)

The internal supervisor is Ingerid Fossum. She assists the group with the project and is available to answer questions. The group will have weekly meetings with the internal supervisor.



3 Project model

When working on any more extensive project, the need for a project model arises. Without a model to base the design process on it is a more significant chance for project failure and less chance of stakeholder acceptance of the end result. A project model is a guide to help the team through the process and reach an acceptable product that considers all the requirements. The model helps the team to allocate time, set deadlines, find out what the stakeholder requires and guides the team in what to work on and when.

As students, we lack in practical experience, and therefore it is even more essential that we use a good project model. The model will provide us structure and help us plan out the entire process. In this chapter, we discuss different project models and the reasoning behind our choice.

3.1 Model choice

There are numerous different ways to approach a project, and one of the first steps should be to select a model on which to base the system development on. Every project model has its strength and weaknesses which means that the group must find the one that fits them the most. Our requirements to the model are that it enables the opportunity to make iterative changes to the system, produces documentation and makes it easy for each group member to follow the process. The purpose of this project is to learn, and therefore the model also should give us the chance to review the work we have done and correct mistakes.

Project models that were quickly excluded were the waterfall– and the V-model. The waterfall model is a linear sequential approach that “floats” in one direction. (U.S. Department of Transportation, n.d.) If you are working with technology and have a clear idea of what the system shall be, then the waterfall model is an excellent choice. The V-model was developed in the 1980s and encourages active verification and validation to enable a more iterative workflow. In our experience, the V-model quickly devolves into a glorified waterfall process because of the linear workflow it presents.

Another model we looked at was scrum, which is an incremental and iterative model. (Schwaber & Sutherland, 2017, s. 3) Scrum is not per se a project model but more a framework which people can address complex problems. One of the disadvantages with scrum is that the lack of documentation it produces.

We chose to base our model on the Unified Process. It has similarities with scrum, as it is iterative and incremental. It gives us the opportunity to produce documentation and it's easy and simple to understand. The Unified Process can also be modified and tailored to our project.

3.2 Unified process

Unified process fits the general definition of a process, the team perform a set of activities to transform a set of customer requirements into a product (Scott, 2002, ss. 1, 4). The unified process is designed for software development and focuses on use-cases to drive development forward. However, the unified process is also a generic process framework that easily can be modified to fit any specific project. Activities that are not relevant for a project can be removed or modified, and new activities can be added. The process is divided into four phases that succeed each other during the creating and in the realization of the system. During these phases, the team will work on five workflows that cut across the phases; requirements, analysis, design, implementation and test.

The key elements of the unified process are:

- Iterative and incremental
- Use case driven
- Architecture-centric
- Acknowledge risk

3.2.1 History

The unified process began forming at the hands of Ivar Jakobson in the late 1960s when he worked at Ericsson (Scott, 2002, s. 2). Jacobson and his colleagues modeled a telecommunication system using “blocks” with the lower levels working as a foundation for the upper layers subsystems.

3.2.2 Why modify the model?

Our goal is to design something physical. We have a system where we basically can say the input is water with high pressure and speed, and the output-goal is water with a lower flowrate and less kinetic energy. We are dealing with fluid mechanics, which is a subject that easily can be visualized. The group consists of four mechanical students which result in a generally small focus on electrical tasks and software programming. Our system requirements will be derived either from stakeholder requirements given from Multiconsult, or from guidelines set by the government. We will not apply use-cases to find system requirements.

The workflows in the original Unified Process originate from software development, and they are derived from how a software developer works. As previously described we do not plan to do any software development and thus we changed the names of the workflows to better represent the activities within them. In chapter 3.2.4 we will go more in-depth into the workflows.

4 Our model



Figure 2: Project model timeline with iterations

5 The four phases

Our model, like Unified process, is divided into four life cycle phases which focus on different aspects of the design process. During these four phases the team will work on five workflows that cut across the phases; project administration, requirements, test, research, design & analysis, and test.

Inception

The primary goal of the inception phase is to establish the case for the viability of the proposed system (Scott, 2002, s. 11). Some of the key criteria the team need to meet in the inception phase is Scope, high-level requirements and critical risks.

Elaboration

The primary goal of the elaboration phase is to establish the ability to build the new system given the constraints the project development faces (Scott, 2002, s. 12). This can be financial constraints, schedule constrains and so on. The milestone associated with the phase is to establish most of the functional requirements.

Construction

The primary goal of the construction phase is to build a system capable of operating successfully in beta customer environments (Scott, 2002, s. 13).. During this phase, the team builds the system iteratively and incrementally making sure the system is viable along the way.

Transition

In the transition phase, the goal is to give the customers a fully functional system (Scott, 2002, s. 13). During this phase, the focus is on troubleshooting and correcting faults in the system. At the end of the transition phase the product shall be released. For our part, this phase will consist heavily of completion of documentation.

5.1.1 Workflows

In this subsection, we will provide a brief overview of our redefined workflows. The workflows define a set of activities, and for that reason we will also base the activity plan on these workflows.

Project administration

Project administration is a workflow containing all activities that are non-technical. You can say that the activities in this section will not contribute to any technical solutions or information. This is the first time the group is working on a project of this scale. Creating a project plan, time sheet and Gantt-diagram is activities that will be done in this workflow. Other activities in this workflow may include proofreading, meetings, presentations and more.

Requirements

The primary activities in this workflow are aimed at defining requirements. Requirements set the framework for our system and are a crucial part of the project. Because of this, it makes sense to cluster all the activities concerning requirements into a separate workflow. The requirement workflow is also a workflow in the original UP, but the difference is that the group do not apply use-cases to define requirements.

Research

Research is another workflow that doesn't exist in the original UP. The reason why reaserch is defined as a workflow for itself is that the group will use a significant amount of time on activities connected to research. The group has fundamental knowledge in fluid mechanic, but throughout the project we will have to expand this knowledge further to develop a satisfactory design.

Design & analysis

Activities involving design & analysis are aimed on designing concepts. In the original UP, Design and analysis are two separate workflows. The reason why the group decided to put these together is that it felt like the two workflows would be closely connected throughout the project. The purpose of analyzing is that it can help redefine requirements, discover risks and see problems. Many of the analyses will be dependent on the models made. Sometimes it may be easier to make a model and then analyze it, other times it will be better to analyze first.

Test

To conclude that the have fulfilled the requirements we need to be able to test the system. This means setting up a test specification, schedule when the tests will happen and perform the test. Seeing as the group is to deliver a Parametric model, and not a physical product, most of the tests will be theoretical or in a CAD program.

5.1.2 Iterations

“An iteration is simply a mini-project that’s a part of a phase” (Scott, 2002, s. 17)

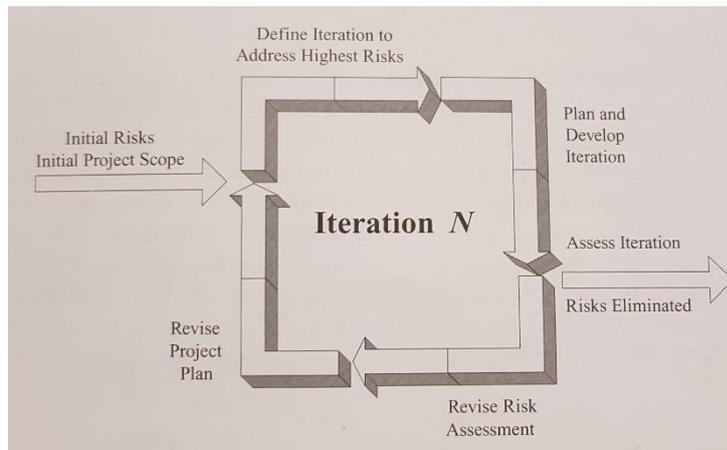


Figure 3: Iterative and Incremental Development (Scott, 2002, s. 17)

The idea behind iterations is to split the main project into smaller ones where each small project contributes to the big picture (Scott, 2002, s. 17). This way of working provides more achievable deadlines which in turn increases productivity. A typical iteration crosses all the five workflows. For example, an iteration during the elaboration phase might focus on activities from the Requirements and Research workflows. The goal

for each iteration is to create an incrementally better system, and thus the result for an iteration is called an increment.

When using an iterative and incremental approach, the group first starts by addressing the critical risks for that iteration (Scott, 2002, ss. 16, 17). Then plan the iteration to a suitable level of detail and perform appropriate activities within the workflows.

After each iteration, an iteration-meeting will be held. In this meeting, an evaluation will be made for the last iteration. What has been finished and what hasn't, what was good and what was bad, areas to improve in and what to bring along to the next iteration. A rough description of what's going to be done in the coming iteration is already made in the project plan. Further planning will have to be done as to who does what and to which deadlines.

5.1.3 Milestones

In a project, a milestone represents a goal, the end of a phase or a deadline. One way of looking at it is that if an iteration is a mini-project, then a milestone is a medium-project, compared to the entire project. A project consists of multiple milestones, which consists of iterations. Same as with the iterations, a milestone is a way of breaking a project down into smaller more achievable deadlines and activities.

In this project, the group has a couple of milestones to reach. These milestones are set by the group itself, the school, and some even by the employer, Multiconsult. The group has split the project into four phases. At the end of each of these phases, a natural milestone occurs. E.g. in the Construction phase, the goal is to complete the calculations and design for the valve. When these criteria are met, the milestone is reached.

6 Time management

This chapter contains an overview of how many hours we have at our disposal and how we distribute and register them. This project is substantial in size compared to previous projects the group members have worked on before and the necessity to organize more thoroughly arises.

By creating an activity plan, the group gets a better idea of how to organize the time and project. As previously mentioned, this is the first time we work on a project of this size, and thus there are multiple uncertainties. The activity plan, iteration plan, and other time management plans are subjects to change. The methods used to create the activity plan gives us the opportunity to compare our time estimates to how many hours we actually use on each activity.

6.1 How much time do have at our disposal?

In order to estimate and allocate the time at disposal, the group need to find how much time is needed. The bachelor thesis is worth 20 credits and according to ECTS this will require between 500 to 600 hours of work. This amounts to 2000 to 2400 hours at disposal between the four of us.

Keeping this in mind there is now possible to distribute the time over the course of the semester. During the first half of the semester there is also another subject, mechatronics. The lecture for mechatronics will be on Mondays and thus this day is primarily for studying this. After the easter, the mechatronics exam will be finished. From this time the group will work five days a week.

If for some reasons the iterations objective does not get finished to the set date, the group will dedicate the weekend to allocate more time. It is always important to try to finish each iteration before starting a new one. The following diagram illustrates the how much time is dedicated each week.

week 1	10	hours
week 2	90	hours
week 3	110	hours
week 4	110	hours
week 5	110	hours
week 6	110	hours
week 7	110	hours
week 8	110	hours
week 9	110	hours
week 10	110	hours
week 11	110	hours
week 12	84	hours
week 13	holiday	
week 14	84	hours
week 15	140	hours
week 16	140	hours
week 17	140	hours
week 18	140	hours
week 19	140	hours
week 20	140	hours
week 21	120	hours
Total	2218	hours

Table 2: Estimate of weekly workhours

6.2 Timesheet

Every group member has responsibility to log worked hours. This will give insight both to the group and active stakeholders on how much time used. Every member has their own timesheet containing diagrams showed underneath. The members will also log their hours in the activity plan. This will be explained in the next chapter.

Slutten på uken:	25.03.2018
Dato	Hours worked
19.03.2018	
20.03.2018	
21.03.2018	
22.03.2018	
23.03.2018	
24.03.2018	
25.03.2018	
Total hours	-

Table 3: Timesheet

6.3 Iteration plan

Iteration is a great tool to handle a large and complex project. In *Figure 5* you can see the project model. The project lifecycle is divided into several phases and these phases are again divided into iterations.

Each iteration is described by a letter and a number. For example, E2 is iteration number two in the elaboration phase. The iteration plan is located in the iteration document (see *Appendix D*).

6.3.1 The iterations

I1: Startup

Period: 03.01.18 – 14.01.18

The focus in the first iteration is to start the project and develop an understanding of what our project goal is. This involves choosing a project model and familiarize it, roughly understanding the project and agree on work ethics. Milestones for this iteration is to have a draft of the project plan and most templates ready.

E1: Requirements specification

Period: 15.01.18 - 25.01.18

The priority in this iteration is tasks concerning the requirements. This involves understanding the requirements from stakeholders and creating our system requirements.

E2: Test specification and plan

Period: 26.01.18 – 06.02.18

In the second and last iteration in the elaboration phase, the focus is on creating tests for the requirements. When working with creating test, the group will also be validating the requirements. The milestone for this iteration is the first presentation. Goals for the iteration is therefore to have a project plan, requirements specification, test specification and test plan complete.

C1: Concept research

Period: 07.02.18 – 25.02.18

The focus in this iteration is research within the technology, production methods, and fluid mechanic. Research and concept development are activities that can be done in parallel. The goal of this iteration is that the group will have at least four concepts.

C2: Concept choice

Period: 26.02.18 – 12.03.18

In the concept choice iteration, we will be working with these four (or more) concepts and compare them to each other. This iteration is one of the most critical iterations for further work. The milestone for this iteration is the second presentation where we will present our choice of concept.

C3: Design

Period: 13.03.18 – 22.04.18



In the third iteration of the concept phase, we will focus on creating a parametric design of the system, document sketches for production and cost of production. Some tests will also be done in this iteration to ensure that the parametric design fulfills the requirements. The goal for the iteration is to a nearly complete parametric design, document sketches for production and cost of production.

C4: Test

Period: 23.04.18 – 10.5.18

In the final iteration of the construction phase, the group will test the system to see if it satisfies the requirements. When testing the system, it will most likely result in some minor changes to the design to optimize it even further. The testing will mostly be done by flow analysis and finite element method analysis. Goals for the iteration is to finish all the tests.

T1: Delivery

Period 11.5.18 – 31.5.18

The primary goal of this iteration (and phase) is to deliver a working version of the system. This involves all the necessary documentation that will be collected into one report. There are two milestones for this iteration, documentation deadline and the final presentation.

6.3.2 Gantt-diagram

The Gantt-diagram is a tool used for planning and management of a project. The graphical representation of tasks, milestones and distribution of responsibility leads to better overview and predictability. The chart gives an overview of the planned tasks, when they are scheduled to start and how much time is allocated to each task. Each task in the chart also states who is responsible for that task.

We used Microsoft Project to create our Gantt-chart. Since none of the group members had created a Gantt-chart before, Microsoft Project gave us an accessible introduction and was easy and intuitive to use.

Our Gantt-diagram show the different iteration and in which phase they are and important milestones such as presentations.

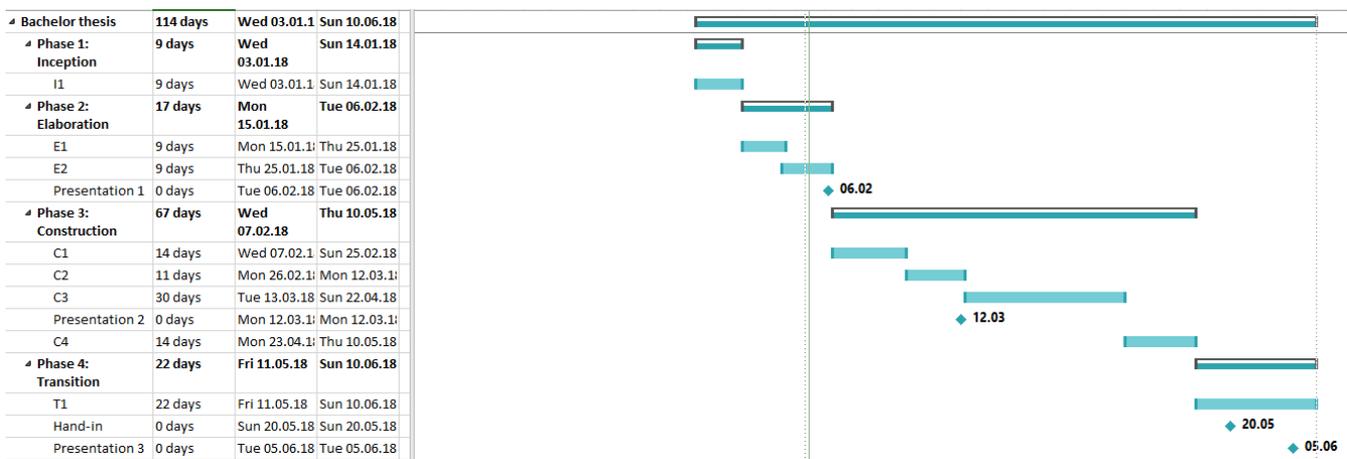


Figure 4: Gantt-diagram

6.4 Activity plan

As mentioned earlier the group will base the activities on the workflows that initially were created in our project model. This will give the project a better entirety. It also makes sense to have a connection between our project model and activity plan. This will make it easier to follow the model and will hopefully result in better execution of the project. The activity plan will give an overview of activities and the consumption of our hours throughout the project lifecycle. We will also use the activity plan write down how much time the group are using on each of the activities. At the end of the project, the group can compare the estimated time and actually used time..

The project plan is shown in Table 4: Activity plan. Instead of creating two activity plans, one with estimation and one with actually worked time, the group felt it would be better to put them together in one plan. Excel gives the opportunity to hide columns, so when we are working on the project, the only visual parts will be those concerning the actual hour use. This way the timesheet is easily understandable and contains everything we want.

A brief explanation of the diagram:

Workflows & activities:

This column contains the workflows in the project model and under each is the activities that belong to them.

Iteration

This is the iterations of the lifecycle of the project. Under each is an estimate of how much time we will use one each of the activities in the different phases.

Total est. time

By adding up time used on an activity through every phase, we get the total amount of time used on this particular activity

OO, MH, LH, JS:

This is the initials of each the group member. In these columns we will write down how much time we are using on each of the activities.

Total reg. time:

By adding up the time of each of the group members on an activity we will get the total registered time on each of them.

Workflow & activities		I1	E1	E2	C1	C2	C3	C4	T1	Total est. time	OO	MH	LH	JS	Total reg. time
1. Project administration															
	1.1 Proofreading documents	8	5	5	2	2	2	2	4	40					68
	1.2 Web page	6	4	2	2	1	1	1	1	18					0
	1.3 Meeting minutes	3	4	4	4	4	10	6	6	41					0
	1.4 Presentations	2		20	20	5	1	1	4	102					0
	1.5 Project plan	50	20	20	5	1	1	1	4	17					0
	1.5 Project model	12	3	2						20					0
	1.6 Gant diagram & time schedule	6	2	1	1	2	2	2	4	29					0
	1.7 Activity plan	15	2	1	1	2	2	2	4	0					0
															0
2. Requirements															
	2.1 Create requirement specification doc.	6	2							8					0
	2.2 Requirement specification		40	20	5	2				67					0
	2.3 Updating requirement doc		10		10	5	4	2		31					0
										0					0
3. Research															
	3.1 Research		30	30	80	60	30	10		240					0
	3.2 Training in new software		25	50	50	20				145					0
	3.3 Production methods		10	15	35	20				80					0
	3.4 Research papers				45	30				75					0
															0
4. Test															
	4.1 Test analysis				15	20	25	30		90					0
	4.2 Test specification	4	15	35	5	4	2			65					0
	4.3 Carry out tests						5	40	5	50					0
	4.4 Test report			10	4		2	20	8	44					0
5. Design & Analysis															
	5.1 Cad modelling				20	20	100	30		170					0
	5.2 Flow analysis				20	40	80	30		170					0
	5.3 Finite element method analysis				15	35	60	30		140					0
	5.4 System control analysis						15	35		50					0
	5.5 Risk analysis	20	4	4	4	4	4	4	15	55					0
	5.6 Cost/benefit report					10	55	35		100					0
	5.7 Concept development			5	100	50				155					0
	5.8 Concept analysis				30	70	20			120					0

Table 4: Activity plan

7 Meetings

Meetings are an important tool to track the progress and keep the group members and supervisors updated on the status of the group and project. It is also used to get feedback. Every meeting has a secretary that takes notes during the meeting and shares it with the group members, internal and external supervisor. It is the project group's responsibility to call and hold meetings. Every member of the group must attend every meeting as long as it is feasible.

The meetings are divided into three categories; iteration meeting, internal supervisor meeting and external supervisor meeting described below.

7.1 Iteration meeting

For every iteration, the group has an iteration meeting. Here we assess the work that has been done the previous iteration, and plan what needs to be done the following iteration. The subjects discussed in the iteration meeting will be written down in the "*Iteration document*" (see Appendix D). Iteration meetings shall be held at the groups assigned room, 1207.

7.2 Internal supervisor meeting

Every week the group will meet with the internal supervisor to get feedback on earlier work and get suggestions for what to be worked on forward. Meetings with the internal supervisor shall be held at a previously agreed location.

7.3 External supervisor meeting

Meetings with Multiconsult and the external supervisor will either be held in Drammen at their offices, or with Skype. The frequency of these meetings will depend on what phase the work is in and how much supervising the group needs at that time.

8 Presentations

8.1 Presentation one

During presentation number one, the assignment/problem given by Multiconsult will be presented and explained. How the problem is solved best, and what will be done to reach the optimal solution will be discussed. The group will then present an overview of the current status of the project, as well as a tentative plan on what's planned to happen in the future.

Documentation that's to be delivered during this presentation is:

- Project plan
- Requirements
- Test specs

The timeframe of the presentation is 20 minutes, maximum. Then a 15 minutes long questioning will happen. This is the time where the sensors have the opportunity to ask the group questions about the project. After which an individual meeting with the sensor can occur, if the sensor feels that it is needed.

8.2 Presentation two

Similarly to presentation one, the project plan will be discussed. Both the plan for the past, but also for the future. If changes have been made to the plan since presentation one, these will be elaborated. The main topic of this presentation is the chosen concept. Leading up to this presentation, the final concept will be chosen. This means that the design, to a certain extent, will be set. The requirements and testing of these will also be elaborated. As in presentation one, the timeframe is 20 minutes, with 15 minutes to questioning after.

8.3 Presentation three

This is the most important presentation of the three. The presentation is split into three parts; a sales pitch, a technical bit, and a questioning round.

- **Sales pitch**
In this pitch, the technical part is not as important. Consider this as a pitch to a normal person, with no pre-knowledge on the subject, and not an expert. The goal here is to really sell the product, so bragging about the benefits of the product and excluding the drawbacks or lacking parts.
- **Technical**
In this part of the presentation, the technical part of the product will be presented. In addition, the process and development of the product should be presented. This is also the time where the group talks about the project as a whole. The evolution of the group and what's been learned should also be discussed.
- **Questioning**
The questioning will be either individual, or as a group. Present are; the group, sensors and supervisor.

9 Requirements

The requirements for the project is compiled from requirements set by Multiconsult and from guidelines set from the government. These requirement, describes how the system shall function and in which environment. Some of the requirement depends on different design choices and will thus be developed throughout the project.

9.1 Requirement notation

Each requirement is rated according to its priority. They are divided into three categories, A, B and C requirements.

Priority	Description
A- must	A requirement MUST be satisfied, high priority
B- should	B requirements SHOULD be satisfied
C- can	C requirements CAN , low priority

Table 5: Requirement classes

Under is an example of how each requirement is notated. Each requirement is given a name based on the priority. For example, RA-001 where R tells us that it is a requirement, A tells us that it is a A-requirement with high priority and the number tells us that it is the first requirement. Each requirement has a number, and the same number cannot be used again.

Req-ID	Priority	Date	Owner	Type
Unique ID for each requirement	Priority for the requirement	Date for creation	Who required the requirement	Type of requirement, i.e. functional or formal
<p>Description: A tangible, concise and testable description of the requirement.</p>				

Table 6: Requirement form

The requirements can be found in the *Requirement specification* document (See Appendix A).

10 Risk

10.1 Goal

A risk analysis is an analysis that charts the risks for the product, or the risks in a project in general. This is a crucial, as it may prevent disasters. The goal of a risk analysis is to assess the likelihood of a bad scenario happening, and the severity of the scenario, should it happen. Analyzing a risk will also help in understanding the risk, and why it is a risk in the first place. By using the data found, appropriate measures can be made to prevent or lower the risk of a certain scenario. The risk analysis can be used as a tool not only to assess the product and its requirements, but also on the project as a whole. Deadlines not being met, group members being sick, loss of financial support, or even the loss of a document. Everything in life comes with a risk, and it would be impossible to assess each and every scenario, it's therefore up to the group to choose which risk to analyze. An analysis of this kind will not only be helpful in preventing a scenario but will also help when it comes to mapping what shall be done if said scenario happens. This can improve the outcome significantly of an unfortunate scenario significantly. This analysis will focus on the risks to the project.

10.2 Analysis

This risk analysis consists of four parts: identification, severity and probability, consequences, and measures.

In the identification part, the goal is to identify the risks to the project. After this is done, the group will choose a handful of the risks, and analyze them. The choice will be based upon likelihood of the risk happening, and the severity of the risk. Meaning that if something is extremely likely to happen but does not affect the project or product in a major way, it will not be analyzed. Same goes for the opposite. If something severely affects the project or product but is exceptionally unlikely to happen, it will not be analyzed. This causes the group to focus on realistic threats and risks, and not waste time.

The severity part will elaborate on what the severity of a certain situation can be. Meaning what will happen if a risk happens, and in what way it will impact the project or product. By knowing which risks have the highest severity, work can later be done to prevent these risks. In the probability part, an assessment will be made to figure out how likely it is for a situation to occur. If it has a high probability, it should be dealt with.

The group uses the consequences part to chart what will happen if the risk happens. By looking at possible outcomes of the risk, it will be easier to take appropriate measures.

In the measures part, the focus lies on improving the project and product to minimize the risks. In this phase, the focus also lies on mapping out what shall be done if a risk comes through, and a situation occurs. By mapping out the situation and proper measures before the situation occurs, handling the situation will be much easier. It is here that catastrophes can and shall be prevented. For a more detailed view go to the risk analysis document (*see Appendix C*).

10.3 The matrix

To evaluate each risk, two parameters will be used: probability and severity. Each ranging from 1 to 5. The probability indicates how likely it is for a given situation to occur. High probability means that it is more likely to occur, than a situation with low probability. High probability equals to high risk. Severity indicates the impact a given situation has on the project or product. A high score in the severity parameter indicates that the situation will have a sizable impact on the product or project. Same as a low score in this parameter indicates that it will not affect the project or product as much. These two parameters will be multiplied with each other via a matrix. A high final number indicates that the risk must be handled.

The matrix is split into 25 bits, which all are color-coded. Each color indicates the severity of the risk.

- Green means low numbers and that the risk is ok without a problem.
- Light green is low-medium numbers, these risks are ok but should be monitored.
- Yellow for moderate numbers, and means that it should be considered.
- Orange means medium-high numbers. These risks are not ok and should be looked further into.
- Red indicating high numbers, and that it must be handled.

Probability \ Severity	1	2	3	4	5
1	1	2	3	4	5
2	2	4	6	8	10
3	3	6	9	12	15
4	4	8	12	16	20
5	5	10	15	20	25

Table 7: Risk matrix

The risks are separated into two categories: product and project. The risks that are in the product category includes everything that has to do with the product. i.e. the requirements. The risks included in the project category, involves everything that has to do with the project itself, and the people involved. The two categories are differentiated by the Risk ID, where project risks are named R-1.XX, and product risks are named R-2.XX.

10.4 The Chosen Risks

Below are the risks the group has decided to analyze.

Risk ID	Risk
RI-1.01	Multiconsult backing out of the project.
RI-1.02	Group member being sick over an extended period.
RI-1.03	Loss of documents.
RI-1.04	Language-barrier leading to misunderstandings.
RI-1.05	Internal deadlines not being met.
RI-1.06	External deadlines not being met.
RI-1.07	Scope of assignment is too big.
RI-1.08	Low motivation in group.
RI-1.09	Do not get access to necessary equipment for testing etc. in the workshops.
RI-2.01	The valve is not able to hold a water-column of 100 to 300 meter.
RI-2.02	The valve can't withstand a flowrate of 0.5 to 3 m^3/s .
RI-2.03	Cannot control the valve flow rate.
RI-2.04	The valve isn't resistant to cavitation.
RI-2.05	The areas where cavitation occur is not changeable.
RI-2.06	Water velocity at the exit of the valve exceeds 10 m/s.
RI-2.07	The valve isn't satisfactory when it comes to mechanical strength.
RI-2.08	The valve is not in compliance with the guidelines from NVE.

RI-2.09	The valve does not pass basic safety standards
RI-2.10	The valve is not scalable.
RI-2.11	The valve isn't fabrication friendly.
RI-2.12	The fabrication documents don't hold an acceptable standard.
RI-2.13	The product costs more to produce than existing products.
RI-2.14	The valve can't be controlled from a remote location.

Table 8: Risk overview

10.5 Analyzation Matrix

The analysis of each risk will be done through a matrix that the group has made. The matrix includes risk ID, requirement that is linked to the risk, the risk itself, why it is a risk, probability, severity, final risk number, consequence and action to be made. With these simple points, a thorough analysis can be made. As the project risks doesn't link to a particular requirement, "n/a" is filled in in the requirement box.

Risk analysis template:

Risk ID: XXXX	
Requirement	The requirement that the risk is linked to, if it is linked to one.
Risk	Describes the risk being analyzed.
Why?	Why is it a risk? What can go wrong?
Probability	The probability of the risk happening
Severity	The severity of the risk
Risk number	The two parameters multiplied with each other. Final number.
Consequences	Consequences of the situation happening.
Actions	What actions can be made to prevent or minimize the impact of the situation.

Table 9: Risk example

10.6 The Product and Project Matrix

The analyses themselves can be found in the risk analysis documents.

When putting the risks back into the risk matrix, it's easy to see which risks should be looked deeper into and handled, and which risks are fine. When looking at each risk in this matrix, it appears more clearly in which of the two parameters the risks needs improvement. The model below will overall provide a more visual presentation of in which state the risks are.

Probability \ Severity	1	2	3	4	5
1			RI-1.08		
2			RI-1.05	RI-1.04, RI-2.10	
3		RI-1.03, RI-2.03, RI-2.12 , RI-2.14		RI-1.09	
4	RI-1.06, RI-2.01,	RI-2.06, RI-2.11 , RI-2.13	RI-2.02, RI-2.08	RI-1.07, RI-1.02, RI-2.07	
5	RI-1.01,	RI-2.04, RI-2.05,		RI-2.09	

Table 10: Risk matrix with risks

10.7 Iterations

In addition to the standard risk analysis, the group will also do a brief risk analysis of each iteration. At each iteration-meeting the group will evaluate the previous iteration, as well as planning for the next, in terms of risks. This will ensure that the group is aware of the risks of the upcoming iteration and gives it a chance to reflect upon the risks of the previous one and how well the risks were being handled. The group will use these meetings as a tool to improve risk-handling throughout the project.

11 Test

11.1 Introduction

To verify the design, the group have chosen to use a testing approach. This means that tests of the system, a subsystem, or a part of a subsystem will be performed to conclude if it fulfills its purpose to a satisfactory level, based on the requirements. This is an extremely important part of the project, as without testing there is no way of telling if the design is good enough, and the requirements are being met.

11.2 Validate and verify

To test the design, it's important that both the requirements and tests are properly validated. This means that a requirement must be non-negotiable, clear and that there is no question on what it means. For the tests this means that it is conclusive, that it gives a definite answer. If these two demands are fulfilled, the tests will give unmistakable answers which can be compared to the requirements and give a conclusion on whether the tested object failed or passed.

11.3 Testing

The complexity of a test is preferably kept at a low level. This makes it easier to evaluate whether the test was a success or not, and normally provides a more conclusive and definite answer. Keeping the complexity-level low will also significantly decrease the possibility of executing it wrong, simultaneously as it makes it easier to reproduce, should it be done multiple times. Assuming the test is realistic, one way to ensure reliable and accurate results is to do the test multiple times. Each test will therefore be done multiple times.

To ensure that each test is performed correct, the group has decided that at least two group members should be present at each test. This will hopefully result in no tests being executed incorrectly.

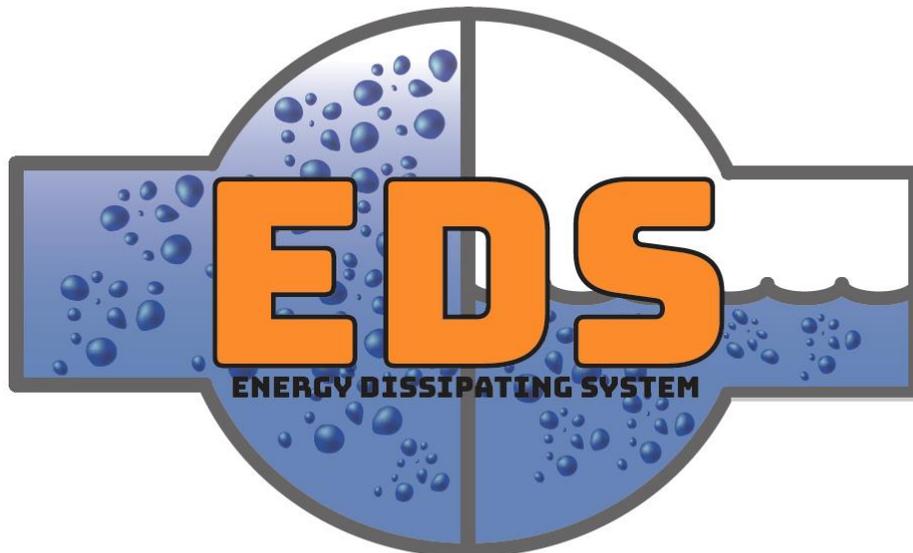
Seeing as the group won't deliver a physical product, but rather a finished design with complete calculations, models and analyses. This means that most of the tests will be theoretical, on models or in Solidworks. This can be both a pro and a con. Because the group won't create an actual valve. The time that would have been spent fabricating the valve can now be used elsewhere. Of course, the valve will have to be modelled in Solidworks, but this won't take nearly as much time as actually fabricating the valve. The con here is that we won't have an actual valve to perform the tests on, which can lead to complications.

The tests can be found in the *Test specification* document (see *Appendix B*).

Multiconsult

Design of bypass valve Concept document

22.05.2018



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Abstract

Background: The task from Multiconsult was to design and parametrize a bypass valve for use in Norwegian hydro power plants.

Method: Brainstorming sessions will be conducted to produce as many relevant concepts as possible. The concepts will then be limited to 10 that both dissipate energy and control the flow rate. These ten will be evaluated within six criteria and put in a Pugh-matrix to choose the best one. The scores will be discussed thoroughly to prevent a misuse of the matrix.

Result: The brainstorming sessions produced 54 concepts that were refined and combined to end up with 10 final concepts. For each of the final 10 a CAD model was produced to help in the criterion analysis. The concepts was thoroughly analyzed in the six criteria and compared in our Pugh-matrix. The scores from the criterion analysis for each concept were discussed with the group members and supervisors ensure that the “right” concept was selected. After the criterion analysis two concepts scored almost equal, concept 7: Movable pipe 3 and concept 10: Maze. After a risk analysis of these two, concept 7 was chosen because this was the most developed concept, and imposed the lowest risk.

Document history

Version	Date	Author	Description
0.00	06.03.18	OO	<ul style="list-style-type: none"> Created the document and chapters
0.01	07.03.18	OO	Added: <ul style="list-style-type: none"> “How to apply system engineering.” Pugh matrix with description
0.02	07.03.18	MH	<ul style="list-style-type: none"> Added Complexity Added Final Concepts
0.02	07.03.18	JS	<ul style="list-style-type: none"> Added Challenges chapter
0.03	08.03.18	LH	<ul style="list-style-type: none"> Added Pugh matrix criteria Added cost efficiency Added summaries in cavitation and energy dissipation
0.04	08.03.18	MH	<ul style="list-style-type: none"> Added Brainstorming Changed “How to apply a system engineering approach in the concept development”
1.0	09.03.18	LH, MH	<ul style="list-style-type: none"> Proofreading and finalizing
1.01	18.05.18	JS	<ul style="list-style-type: none"> Proofread
2.00	19.05.18	LH	<ul style="list-style-type: none"> Added abstract Rewrote figure and table texts

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1 Introduction

The task presented to the group by Multiconsult is to design and parametrize a bypass valve to be used in hydroelectric power plants as a more cost-efficient alternative to current bypass valves. The design must be able to control and regulate the flow and dissipate a satisfactory amount of energy, so the water does not destroy internal equipment in the power plant or erode the river downstream. During the course of the last month, through brainstorming sessions and innovative thinking, the group have produced multiple concepts. These concepts have been narrowed down to ten chosen ones. All of these concepts are able to fulfill the most critical requirements for the system. To choose the best possible concept, each concept will be analyzed in a set of criteria, and then apply a Pugh-matrix as a tool to help choose between them.

2 Challenges

When designing a valve, several challenges arise. In this chapter, some of the most critical challenges are explained. The reader should consider that these are not the only challenges encountered, but rather a selection of the most prominent ones. It should also be noted that not all of these are challenges, but areas of the system that require more attention.

2.1 Energy dissipation

The main task is creating a system which works as a bypass for the turbine in hydroelectric power plants. Therefore, it must dissipate the energy the turbine normally would convert to electrical energy. The input in the system is water with a high amount of mechanical energy and the output should be water with less mechanical energy. To decrease the mechanical energy in the water, some energy must be converted to thermal energy.

2.1.1 Friction

The best way to convert mechanical energy into thermal energy is, in this case, through friction (White, 2009, pp. 355-357). When a fluid is moving, the particles in the fluid experience friction against other particles. This friction turns the mechanical energy in the fluid into thermal energy. When the velocity increases, the friction also becomes higher, and so, more mechanical energy is dissipated. Seeing as one of the main goals of the system is to dissipate energy, it will therefore be beneficial to increase the velocity of the fluid.

2.1.2 Turbulence

Turbulence is a phenomenon linked with fluids (White, 2009, pp. 347-354). It measures how the different layers of a flow interact between them. If these layers flow in parallel and with a predictable movement, there is little turbulence. If they are mixed and the path of the particles is chaotic, the flow is turbulent. Turbulence increases the energy dissipation, as it increases the friction between particles of different layers. Therefore, a goal when designing is to induce turbulence. A way to increase turbulence in a fluid is to increase the velocity of the fluid.

2.2 Cavitation phenomenon

Cavitation is a dangerous phenomenon that can occur when there is a pressure drop in a system, for example in a valve (Lide, 2004, pp. 6-8). At low pressures, water will boil at a lower temperature, for example, at 2.33 Pa water boils at 20°C.

This will cause the water inside the valve to vaporize. When the vapor bubbles flow to a higher pressure-zone, they will implode. This implosion can cause damage if it happens close to a solid surface. The danger of cavitation is apparent under prolonged operation; the implosions of the vapor bubbles will erode the material and remove corrosion protection from the surface. The effects of cavitation can be seen in Figure 5.



Figure 5: Damage on a pump due to cavitation effects (Schroeder, 2015).

2.3 Conflict with energy dissipation and cavitation

The only way of avoiding cavitation is decreasing the pressure drop, so that no pressure-zones are below vapor pressure. The problem is that having a lower pressure drop means less acceleration. This means that there are “speed limits” when it comes to designing systems for water. And, as seen in the chapter 2.1, high velocity is good for dissipating energy. Therefore, cavitation is the limiting factor for the speed of the fluid, and so, for the energy dissipated.

2.4 Cost efficiency

For the concept to be a viable option, it must be cost efficient. The problem is not how to dissipate the energy and avoid cavitation, but the amount of money it costs. One of the stakeholder requirements is that *“The valve should cost less than current alternatives”* (see Appendix A) which has been a focal point for the design and concept selection process. The price of the valve is affected by several factors. These factors are explained, evaluated and discussed in the selection process, Chapter 6.4.

If the price for the valve is too high, it will decrease the number of hydropower plants that can afford to install it. The profit margin for a small sized hydropower plant may diminish or disappear completely if a costly valve is installed. To maximize the number of potential customers, it is crucial that cost is kept as low as possible.

3 How to apply a system engineering approach in the concept development?

The project plan (*see Project Plan*) states that the group is using an iterative project model. Where the project's lifecycle contains several iterations or "mini-projects". The iterations give the opportunity to evaluate and validate the work throughout the project. When developing concepts, the group will implement a system engineering methodology. Even though concept development should be an open minded and creative process, it is important to have some sort of structure. One of the measures done is to split the brainstorming into three sessions, thus making it an incremental way of working. This gives the group the opportunity to evaluate each concept, and the progress made. When evaluating the concepts from the brainstorming sessions, it will be prominent if the concept fulfils the core requirements.

The concept phase has been completed by using an incremental approach. Most of the early concepts are simple drawings with an idea of a design that could fulfil the intended goal. Through the brainstorming sessions, the concepts became more detailed. This means that the group had the chance to do basic simulation on each concept. Underneath is an illustration of an incremental approach. The illustration shows how the "Energy dissipating box" concept incrementally improved from a basic sketch to a detailed final concept.

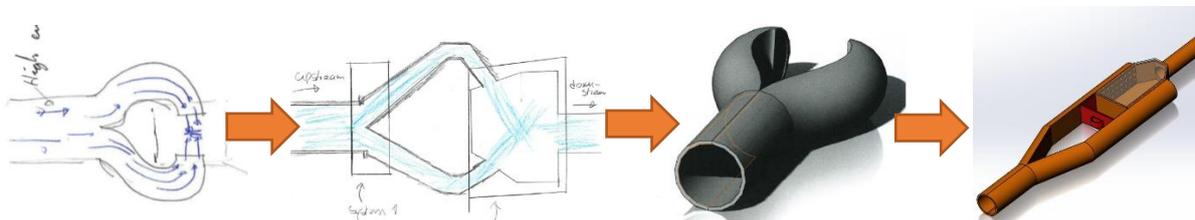


Figure 6: Illustration of an incremental process, using the concept Energy Dissipating Box as an example

4 Brainstorming sessions

4.1 Introduction

Although there are many parameters, requirements and criteria set for the system, there are still numerous different ways to fulfill them. It is therefore advantageous to have a wide selection of systems to choose from, which increases the chances of making a better system in the end.

As the system should both regulate flow and dissipate energy, a system that handles either of these is valuable. If a system is incomplete, meaning that it lacks either flow regulation or energy dissipation, it can be combined with another system to make a complete system.

The same goes for a complete system. If a system is complete, but could perform better, it can be combined with another system. For complete set of concepts see Concept Gathering (see Appendix E).

4.2 Goal

The goal of the project is to develop a system that both regulates flow and dissipates energy. This will naturally be one of the goals of the brainstorming sessions as well. However, the main goal of the brainstorming sessions is to create a platform that the group can develop further. The concept does not have to be perfect at the beginning, but it must have potential. The concept can be refined at a later stage. The important part is to create a good and solid baseline. A concept that the group can work on further and continue to develop.

4.3 Way of working

The way the group decided to do the creative process is by having brainstorming sessions together, where the group would work on the concepts together. As well as sessions where each group member was working on the concepts alone.

This means that during the brainstorming sessions the group gather up to decide what the session will be about, e.g. an exercise, a specific type of valve etc. After the goal of the session has been set the group would always do a particular exercise. A time limit would be set, and the group members could go and work on the concepts until the timer rang. When the time is up, each group member had to present the concepts and give feedback to each other. This way the group would produce more concepts, while working together, inspiring each other and giving each other ideas.

In between the sessions, the group members had the opportunity to work further on the concepts they wanted. This time is also a great opportunity to discuss each concept more in depth.

4.4 Brainstorming 1

As mentioned earlier, having many concepts to choose from is preferable and advantageous. The group therefore had to come up with said concepts. To do so, the group took advantage of some brainstorming exercises. These exercises are taken from Slagkraft by Erik Lerdahl (2007). These exercises are meant to free the mind and get the creative juices flowing. The first exercises used are based on making loose, extreme and crazy concepts. There are no wrong answers, and the group could look away from physics etc., to some degree. This way of working would really get the creativeness going as well as breaking barriers within the group. Although the concepts may be too crazy and unrealistic, it is almost certain that some aspects of some of the concepts could be used (Lerdahl, 2007).

As expected, the exercises gave results. Throughout the brainstorming sessions the group came up with a total of 54 concepts, many of them rooting back to this session. These concepts are all documented in Concept Gathering (*see Appendix E*).

4.5 Brainstorming 2

During the second brainstorming, the group had to get a little more specific. Some of the concepts from this session are concepts from brainstorming session 1 that has been developed further, while other are new concepts.

In this phase the group focused more on the valve rather than the energy dissipation, seeing as in brainstorming session 1, most of the concepts were focused on energy dissipation. This led to several new valve concepts, and as expected not that many pure energy dissipaters.

4.6 Brainstorming 3

In this brainstorm the group had to put everything together. The goal for this session was to make the concepts as complete as possible, ready for evaluation. Meaning that each system that the group wanted to work further on had to both dissipate energy as well as regulate the flow.

Making use of the concepts the group had already produced, the group started combining various concepts to develop a concept that satisfied the goals. As mentioned earlier, the main goal of all these brainstorming sessions is to develop a concept or multiple concepts that dissipates energy and regulates flow. Later each concept can be refined to perform the tasks better.

The group got a request from Multiconsult stating that they wanted the group to look into a “maze-concept”. This is an idea that is in use today, but not as a bypass system.

5 Final concepts

5.1 Introduction

These are the ten concepts that the group has chosen. They have been chosen as they have the most potential out of all the concepts created.

This document will describe how each concept works, where the inspiration came from as well as pros and cons for each concept.

5.2 Bucket

5.2.1 Introduction

This concept is one of the concepts that has been around from the very start. Although it has been known about it for so long, very little work has been done to improve the design. This means that there are still plenty of opportunities left to improve and develop the design. As the concept on its own doesn't regulate flow, it had to be combined with a valve of sorts. The concept will work with most flow regulating valves and the valve chosen for this version of the concept is the "movable pipe 3". This valve is described later in the document.

5.2.2 Concept

The concept is based on a bucket design. The idea is filling a bucket/reservoir and letting the excess water run over the edges and continue downstream.

The water will enter the bucket through a vertical pipe. In the bottom of the bucket there is a cone, splitting the water and forcing it to the edges of the bucket. After a short period, the water will have filled the bucket. At this point the water will flow over the edges of the bucket. Depending on the bucket-size and the water-restrictors in the bucket, the water will exit the bucket with a certain energy. Even without restrictors, the water will come out with a lower velocity. This is due to the fact that the water is spread out over a larger surface, thus slowing it down. Although the water still has the same energy, since the velocity is lower, it will not do as much harm to the surroundings.

To lower the energy of which the water exits the bucket with, restrictors or fins, will be placed along the walls of the bucket. This will slow the water down by exploiting friction. Another solution is to make holes in the wall of the bucket, in which the water can be let out through.

5.2.3 Valve

Seeing as this concept doesn't constrain the water, it will have to be used in conjunction with a valve. This can be any sort of shutoff valve. Because the bucket handles the energy in the water, the valve will not have to. This means that the valve used does not have to be an energy dissipater, making it cheaper. For this version of the system, the "movable pipe 3" valve has been selected as the valve. This valve both regulates the flow as well as dissipating some of the energy. The valve is described in detail under the "movable pipe 3" chapter.

5.2.4 Model

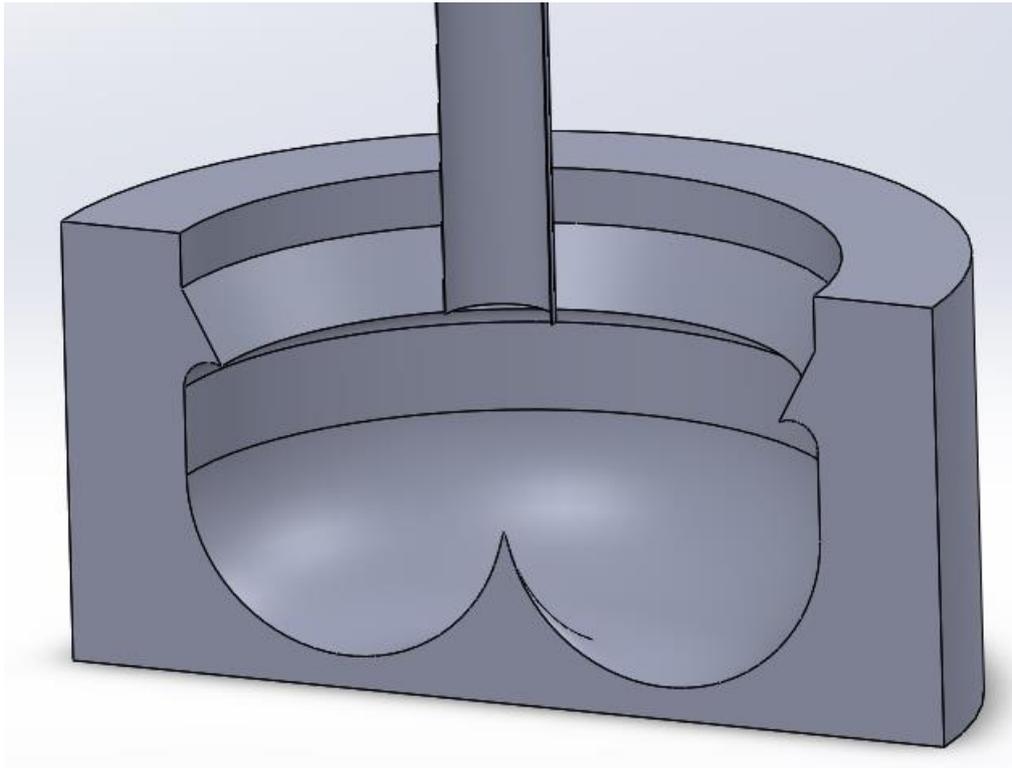


Figure 7: Cross sectional picture of the bucket concept

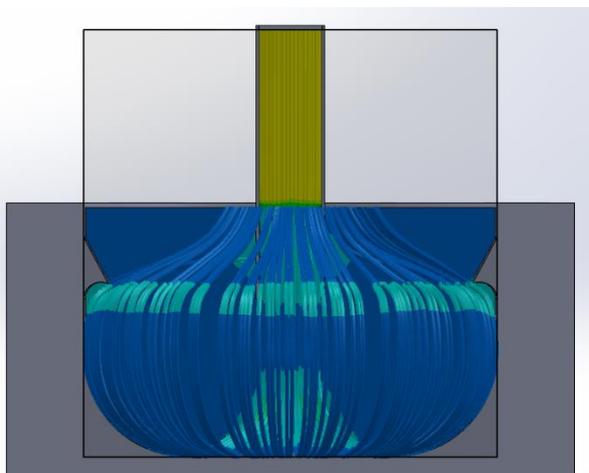


Figure 9: Flow trajectories in the bucket. The flow is entering at a higher pressure in the yellow area and the pressure quickly decreases

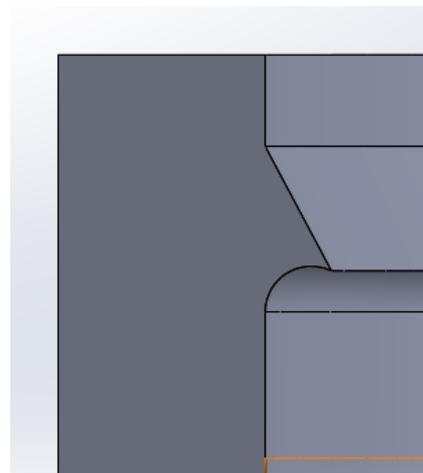


Figure 8: Water redirector

5.2.5 Preliminary Pros and Cons

Pros	Cons
Very simple	The bucket must be used in conjunction with a valve
No moving parts in the bucket	Depending on the facility, the bucket may be huge
Dissipates more than enough energy.	

5.3 Movable pipe 1

5.3.1 Introduction

This concept shares the control mechanism of several other concepts. The idea is to make it easier and cheaper to control the valve. Seeing as several of the groups concepts are based on this idea, they are all called the same only with slight variations in the name.

5.3.2 Concept

The concept is based on having a larger pipe sliding on the outside of the main pipeline. The element inside the pipeline, which is controlling the water, will be attached to this larger pipe. By moving the larger pipe, the flow rate will be regulated.

Often in valves, the steering of the valve is something that demands huge amounts of resources. Both when it comes to designing it, but also when it comes to producing it and of course operating it. This is because the mechanism often require custom made parts, in other words: parts that are not standard. This naturally increases the price of the valve. The conclusion is simple: by simplifying the way the valve is controlled, the production costs will be lowered.

The valve part of this concept is an element in the center which the water will have to flow around. At the edges of this element, the water will be restricted by a plate pressing against the element. This plate has an edge that forces the water towards the center of the pipe.

5.3.3 Model

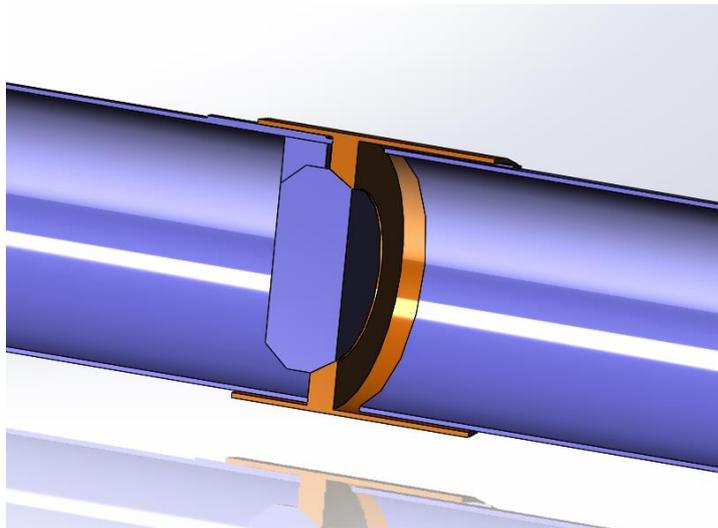


Figure 10: Cross section view of the Movable pipe 1

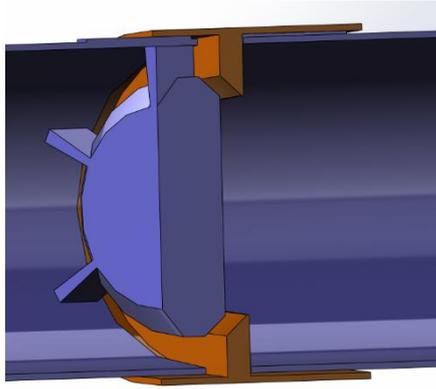


Figure 11: The valve is open

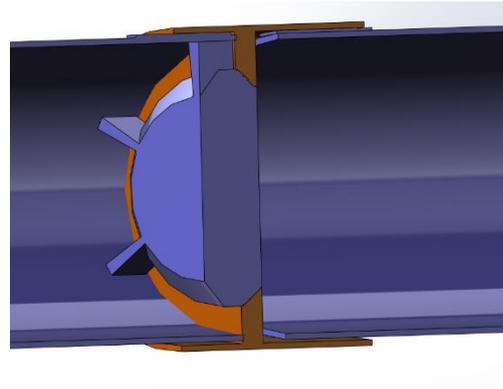


Figure 12: Valve is closed

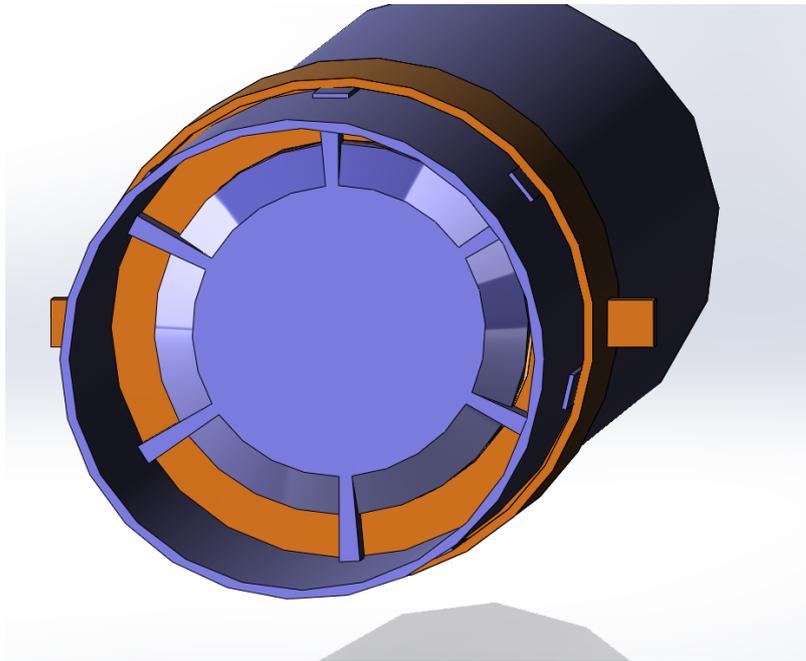


Figure 13: View from the outside of the valve

5.3.4 Preliminary Pros and Cons

Pros	Cons
Regulates flow	Doesn't dissipate enough energy
No cavitation on pipe	Cavitation on parts
Easy to control	Problem with sealing between movable pipes
Simple design/ cheap to produce	

5.4 Jet valve

5.4.1 Introduction

The concept is based on the same principle as the plunger valve and has therefore some similarities. These principles are used in conjunction with inspiration taken from other energy dissipating systems. This led to the jet valve.

5.4.2 Concept

The main idea is to have a widened part of the pipe. In this compartment there will be an element in the center, for the time being this element is a sphere, but this is subject to change.

To control the water, two plates are placed next to each other. These plates reach around the sphere. The plates are perforated to let the water run through. Depending on if the holes in the two plates match up or not, a certain amount of water will be let through. Rotating the plates to make the holes match up better will allow more water to run through.

The idea is that the sphere will suck everything towards the center of the pipe, this includes the cavitation. Thus, preserving the walls of the pipe.

5.4.3 Model

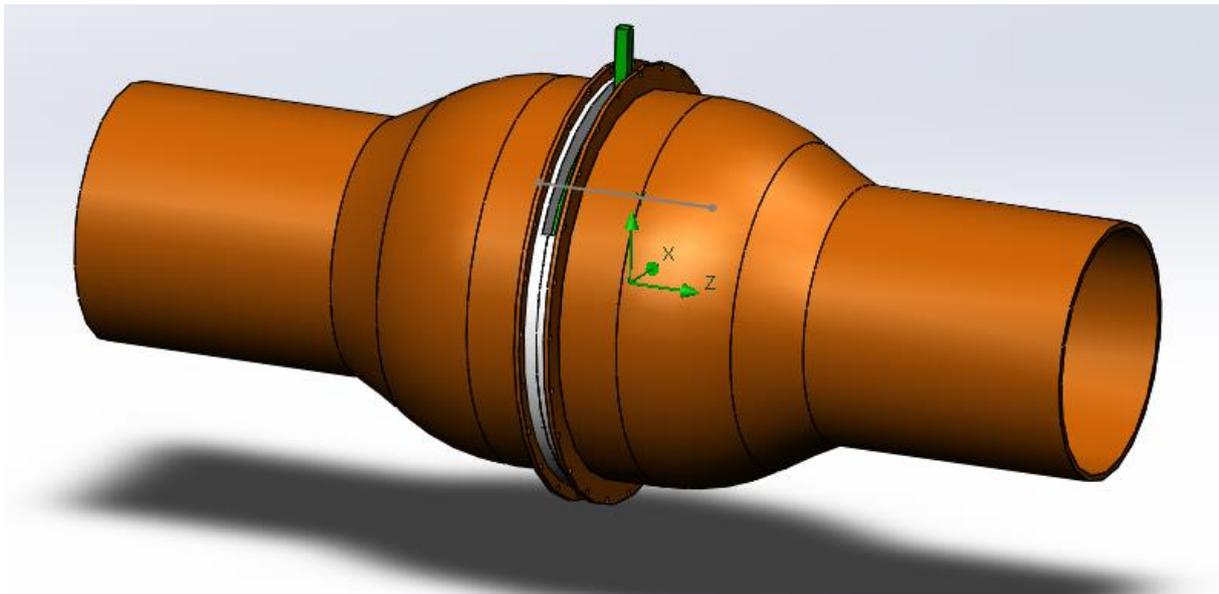


Figure 14: Isometric view of the Jet Valve

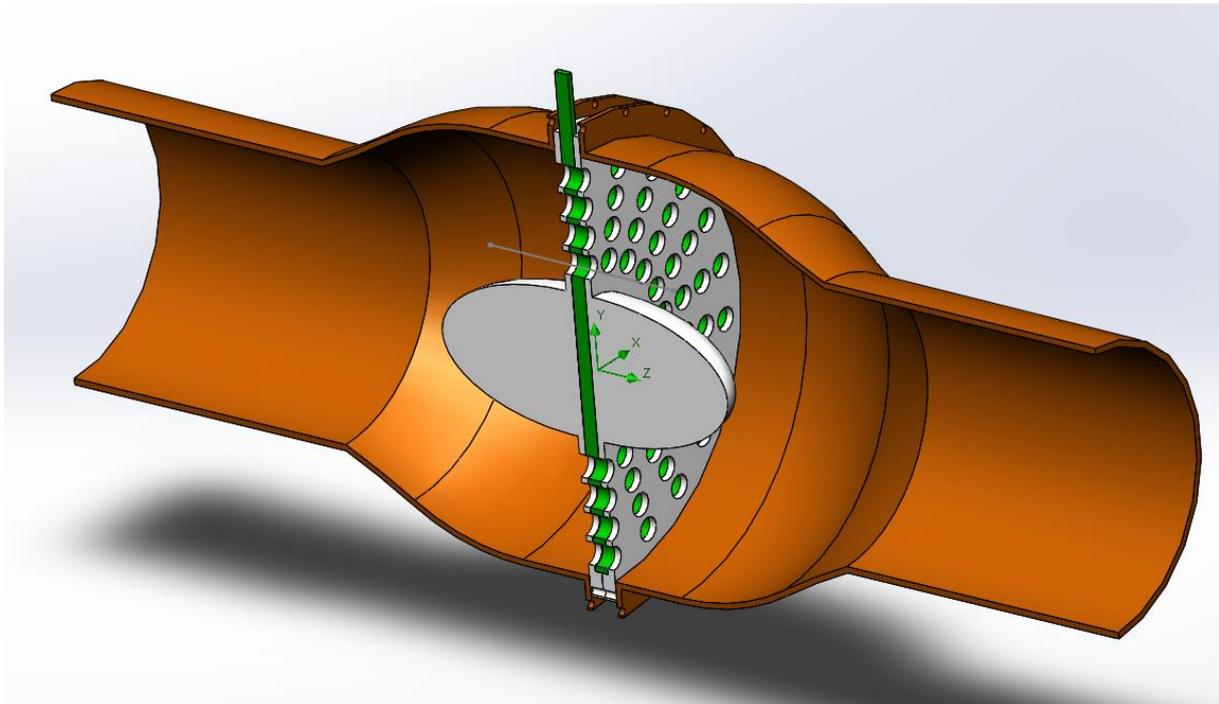


Figure 15: Cross section of the Jet Valve

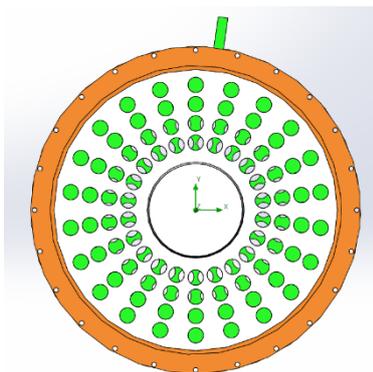


Figure 16: System closed

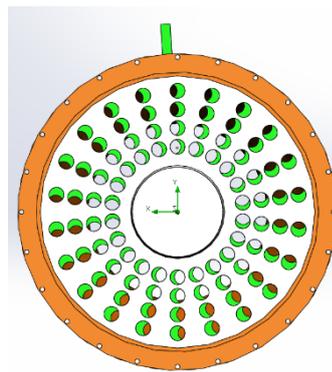


Figure 17: System semi-open

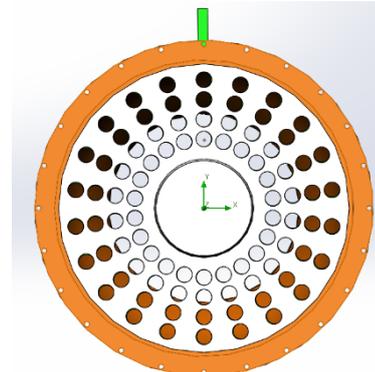


Figure 18: System open

5.4.4 Preliminary Pros and Cons

Pros	Cons
No theoretically harmful cavitation	Can be expensive
Simple control mechanism	Custom made parts
Based on proven principles	

5.5 Movable pipe 2

5.5.1 Introduction

This concept shares the control mechanism of several other concepts. The idea is to make it easier and cheaper to control the valve. Seeing as several of the groups concepts are based on this idea, they are all called the same only with slight variations in the name.

5.5.2 Concept

As with all the movable pipe concepts, the idea is to split the water and use it against itself. This along with the narrowing of the flow-path will dissipate energy.

This concept is heavily based on the usage of custom parts. This can both be a positive as well as a negative factor. This allows it to have more control over the water, where it flows, how it operates etc. naturally this makes it more expensive to produce but should also lead to better performance.

5.5.3 Model

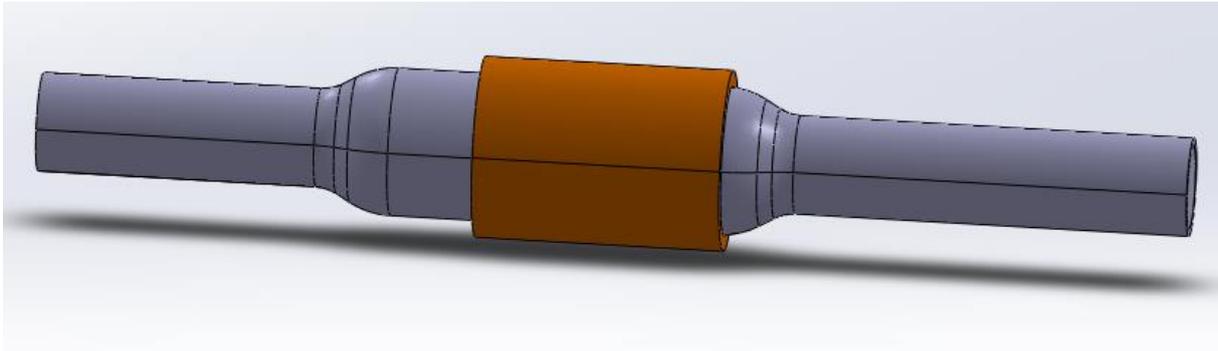


Figure 19: Outside view of the Movable pipe 2

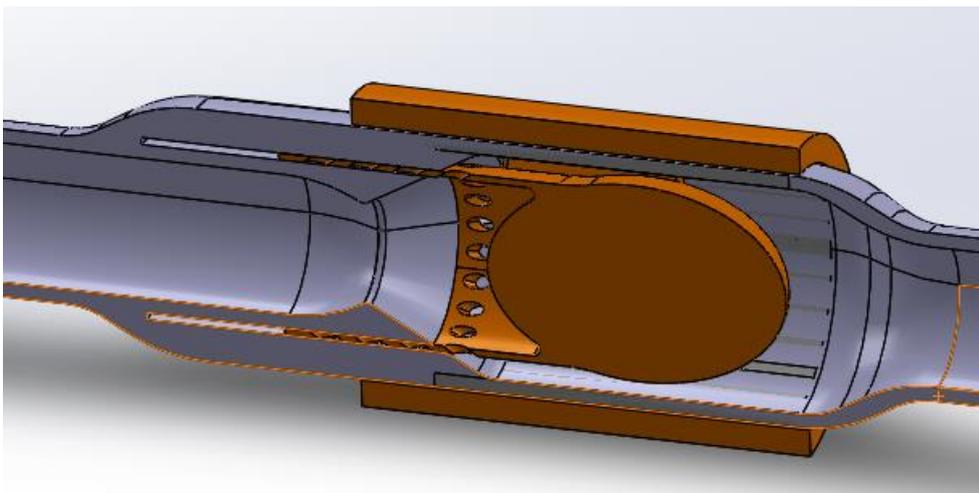


Figure 20: Cross section view of the Movable pipe 2

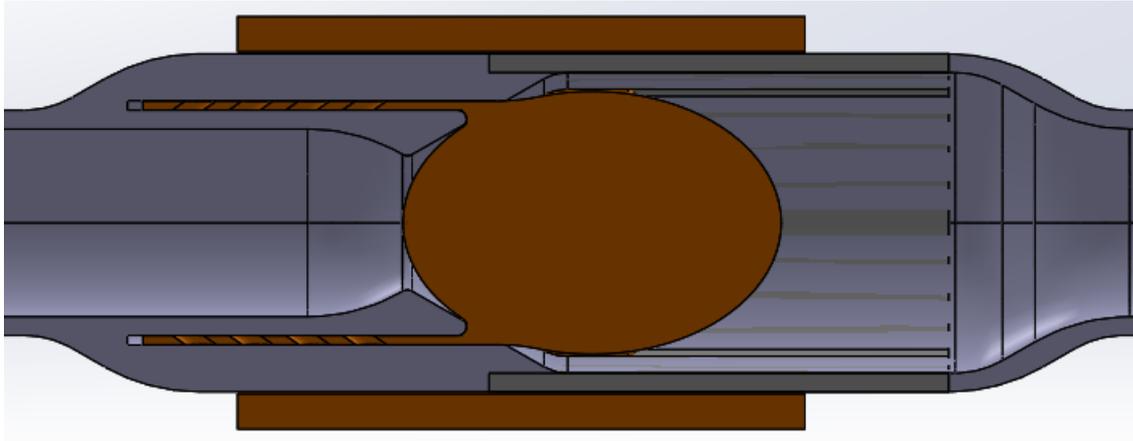


Figure 21: System closed

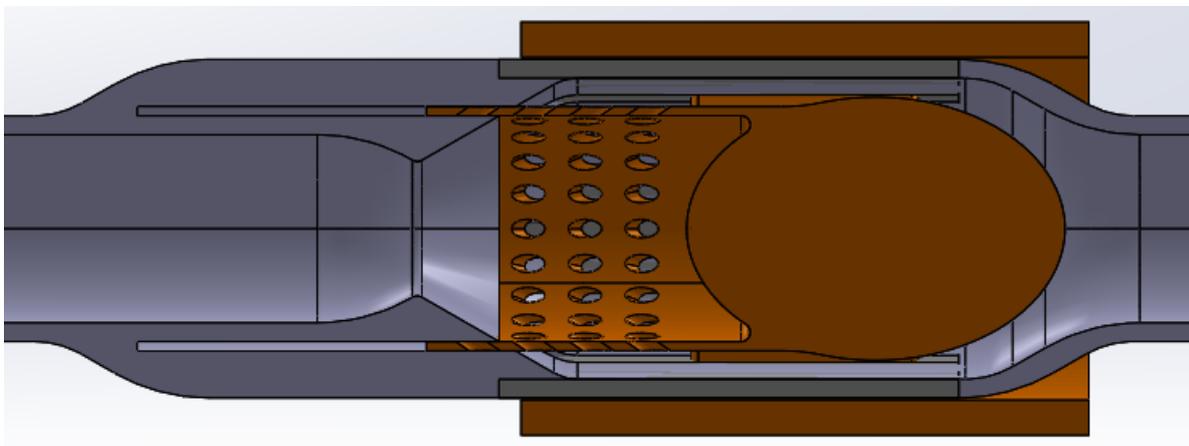


Figure 22: System open

5.5.4 Preliminary Pros and Cons

Pros	Cons
Regulates flow rate	Problem with sealing between movable pipes
Can dissipate energy	Expensive
Simple control mechanism	Custom parts

5.6 Energy dissipating box (EDB)

5.6.1 Introduction

Using water against itself is something that is widely used today, and something some of the group members thought of even before starting working on the actual project. This is a basic idea that are used in several valve systems today. Even though it is widely used, there are still other ways to design a system using this idea.

5.6.2 Concept

The idea is simple, use the water against itself. The basic thought is to split the water into two tubes, then spray these against each other. This means that the cavitation only will occur where the two water-columns meet, in the center of a compartment. This will dissipate the energy, to some degree at least.

To regulate the flow, and to dissipate even more energy, a closing mechanism is introduced. The mechanism is based on several holes between each tube and the compartment. To regulate the flow, these holes will have to be covered. This is done by sliding a “drawer” back and forth to regulate how many holes that are covered.

Seeing as this is a fairly simple construction, most of the parts are standard. Meaning they already are produced and available, making them cheaper.

5.6.3 Model

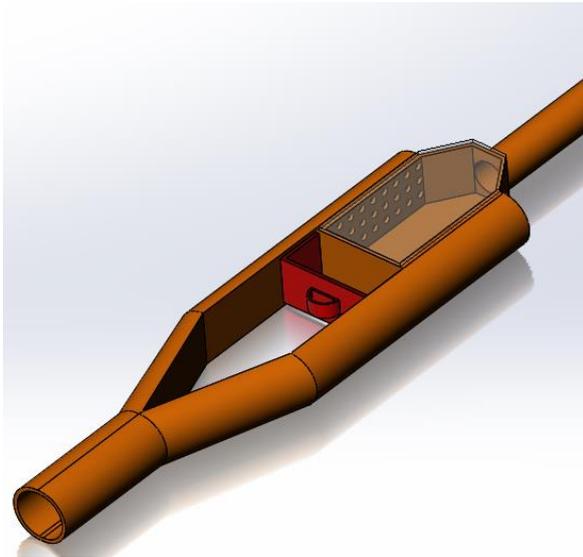


Figure 23: Isometric view of the EDB

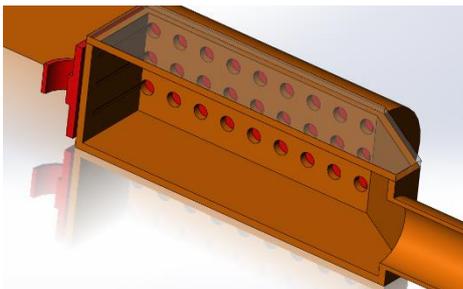


Figure 24: System closed, the “drawer” is pushed all the way in and covers all the holes.

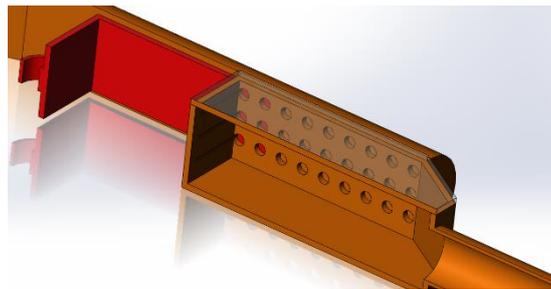


Figure 25: System open

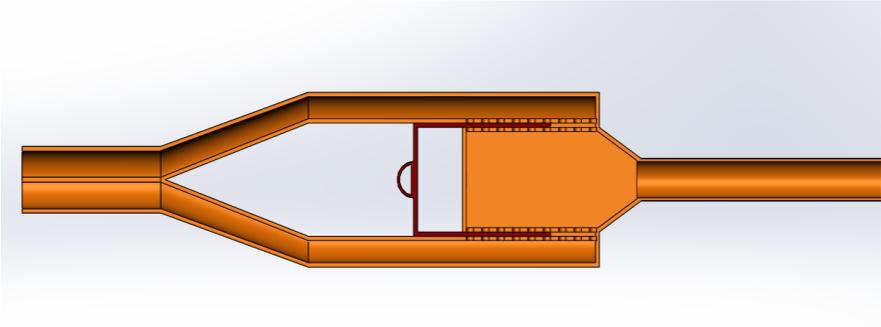


Figure 26: Top-down view of the EDB

5.6.4 Preliminary Pros and Cons

Pros	Cons
Regulates flow	Big in size
Handles cavitation	Hard to get a good seal
Standardized parts	

5.7 Plug

5.7.1 Introduction

In the brainstorming phase the group came up with many concepts. Some of which were disregarded, while others were refined further. This concept, Plugs, is mainly a valve, but with some energy-dissipating capabilities. Depending on how well the group develops it further, this can either be used as a standalone valve, or in conjunction with an energy-dissipater.

5.7.2 Concept

The idea is to have multiple small cones to control the water. This is done by forcing the water through holes in a plate within the pipe. These holes will then be plugged by the small cones. This concept can either be used as a valve in the pipe-system, or at the end of the pipe. Varying the distance between the cones and the perforated plate will vary the amount of water that is let through.

The cones are connected to an outer pipe, which glides on the outside of the main water-pipe. Keeping the mechanism on the outside wil significantly reduce costs. By using this configuration we are also able to reduce the amount of moving parts.

By having multiple smaller holes, compared to one large, the cavitation that occurs will be smaller. This small holes will induce a more laminar flow. Smaller parts are also in general cheaper.

5.7.3 Model

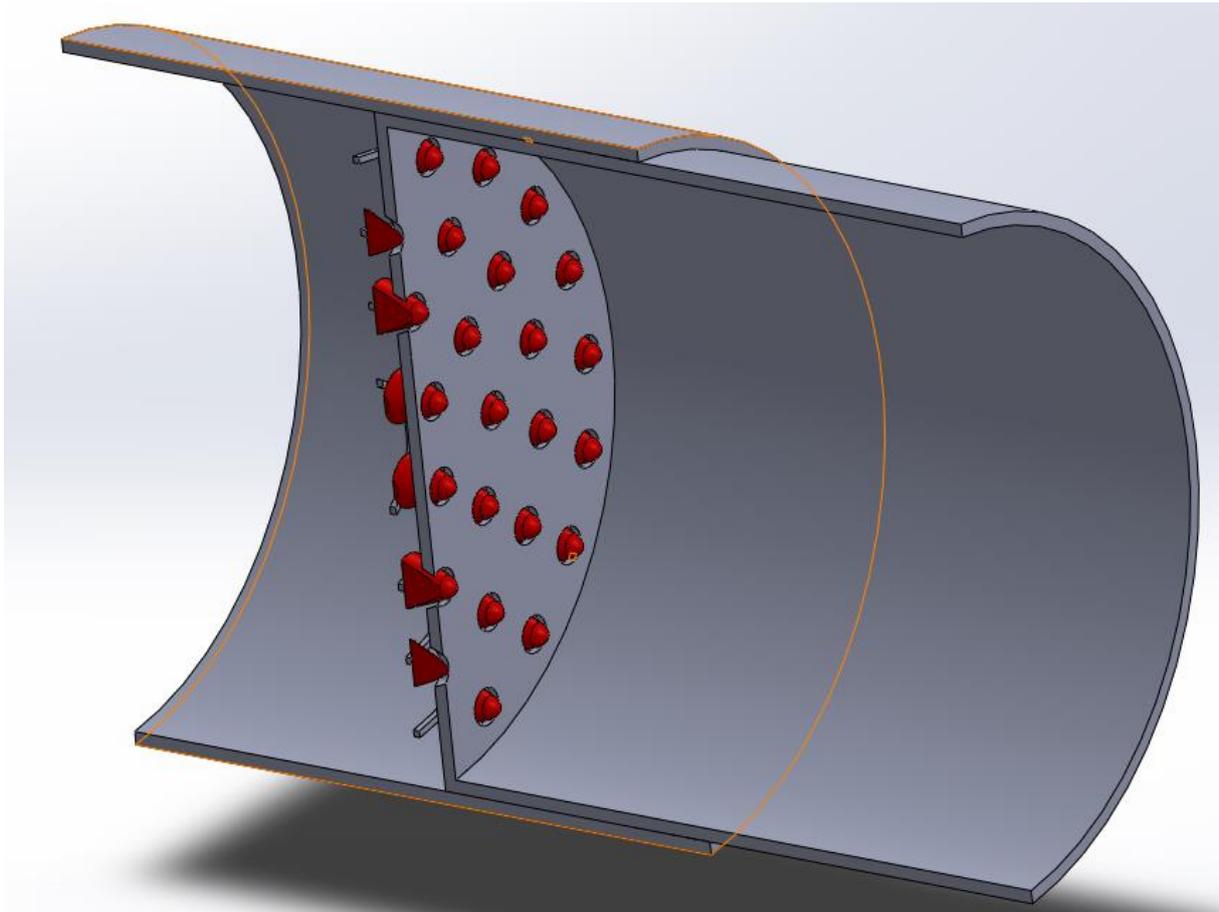


Figure 27: Cross sectional view of the plug concept

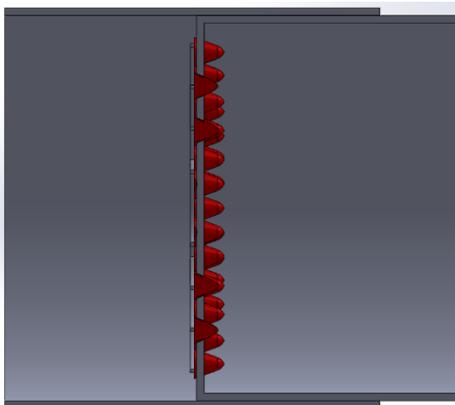


Figure 28: System closed

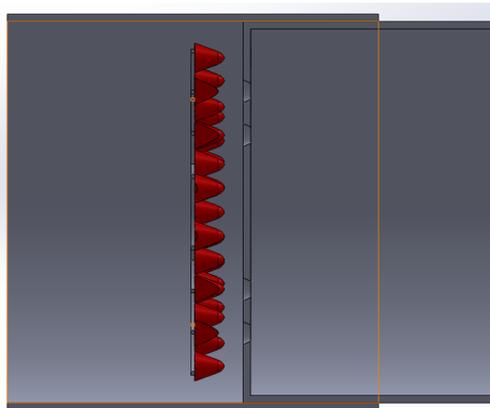


Figure 29: System open

5.7.4 Preliminary Pros and cons

Pros	Cons
Simple mechanism	Many parts -> big assembly
Regulates flow	Doesn't dissipate enough energy

5.8 Movable pipe 3

5.8.1 Introduction

This concept shares the control mechanism of several other concepts. The idea is to make it easier and cheaper to control the valve. Seeing as several of the groups concepts are based on this idea, they are all called the same only with slight variations in the name. By using proven parts and theories, this concept came to.

5.8.2 Concept

The concept has taken inspiration from the plunger valve, in that it uses a cylindrical grid to force the water through. This will significantly increase the velocity of the water but will also dissipate the energy.

The basic idea is to split the water, to later use it against itself. This is done by a cone inside the main pipe. After this cone comes a perforated tube in which the water will be forced through. Seeing as the water comes from all around the perforated pipe, it will spray against itself after being forced through the perforated tube. These two factors will dissipate enough of the energy in the water. The only problem is that they do not regulate the flow.

To regulate the flow, a control mechanism must be installed. For this concept the easiest way would be to cover up the holes. This is done by a pipe sliding on the outside of the perforated tube, covering up a certain amount of the holes. This sliding tube is connected to the outside tube. By moving the outside tube, the flow is regulated.

5.8.3 Model

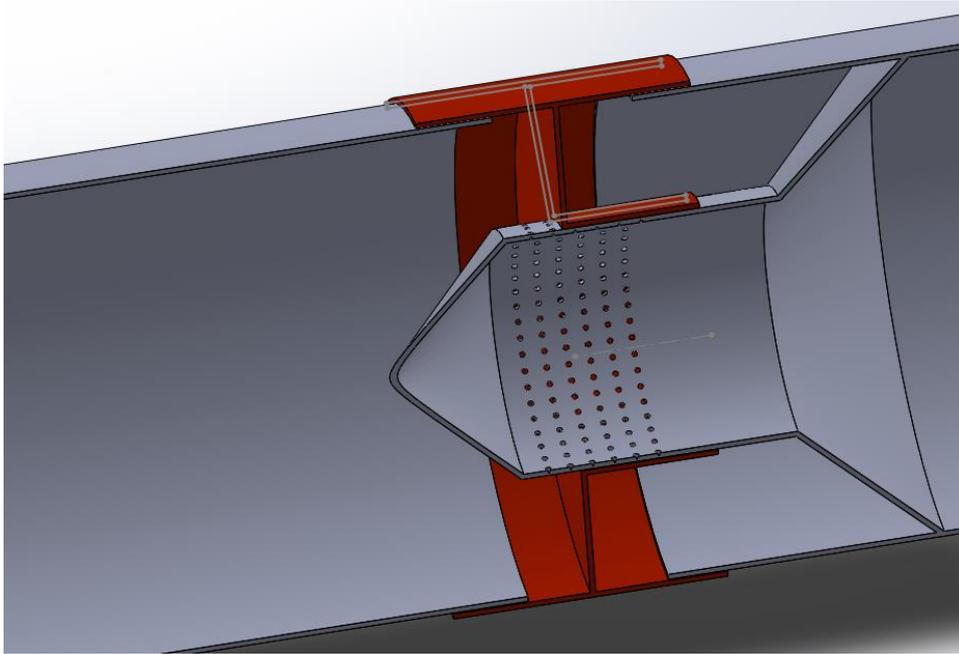


Figure 30: Cross sectional view of the Movable pipe 3

5.8.4 Preliminary Pros and Cons

Pros	Cons
Easy to control	Some custom parts
Simple construction	Problem with sealing between movable pipes
Regulates flow	
Dissipates energy	

5.9 Rock Block

5.9.1 Introduction

This concept was initially just an energy dissipater, without the possibility to regulate the flow. This concept was at a later stage combined with another concept, a valve. These two concepts combined then formed a single concept, Rock Block.

5.9.2 Concept

The idea behind this concept is blasting the water into a hard surface, dissipating blocks, to dissipate the energy. The water will erode the dissipating blocks over time so they will eventually have to be replaced. The goal is thus to find a cheap material for these blocks, like stone. The initial idea was blasting the water into a rock wall or the mountain. The problem here is that not all facilities have access to a natural rock wall. Therefore, this wall would have to be manmade in some cases.

The solution was a metal net-box filled with rocks. This solution is better than blasting the water into a stone wall, as the water has the possibility to continue onward in between the stones in the box, reducing the splash and increasing the energy being dissipated. The boxes will be placed at the end of the pipe downstream.

To control the flowrate, a valve is needed. The main task of this valve is to regulate the flow and ensure that most of the fluid flow is directed into the rock blocks. The valve chosen is a variation of the valve in the “movable pipe 1” concept. Only this time placed at the end of the pipe. As in the “movable pipe 1” concept, it regulates the flow by sliding the outer tube back and forth.

5.9.3 Model

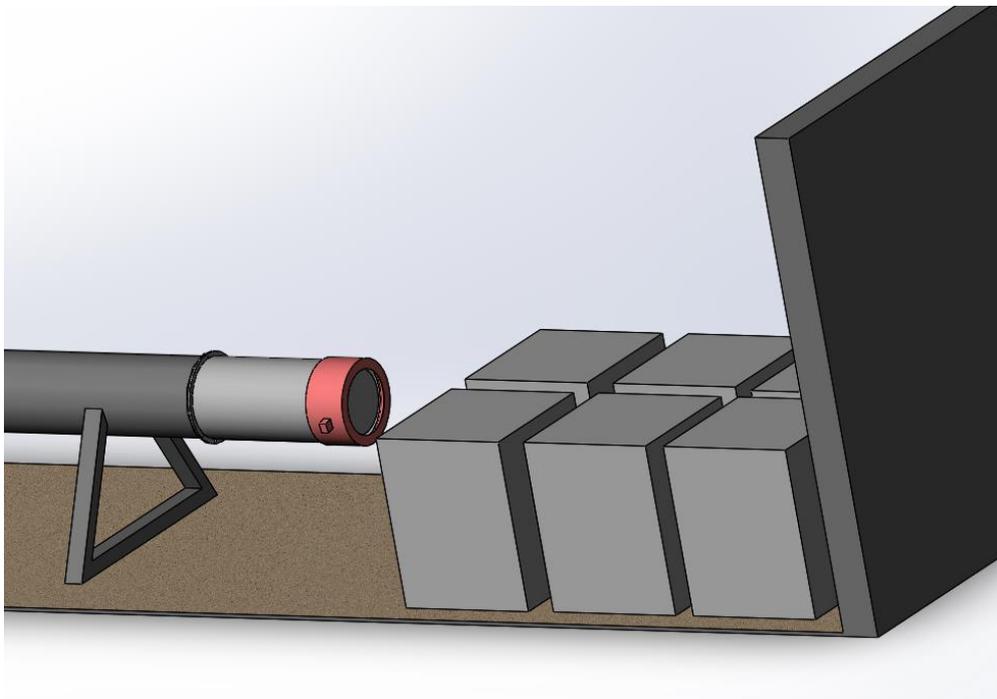


Figure 31: Isometric view of the rock block with a flow regulating valve

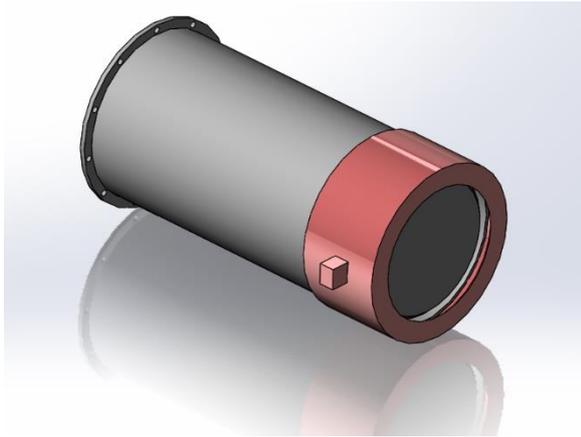


Figure 32: The flow regulating valve

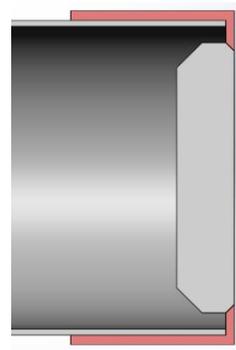


Figure 33: System closed

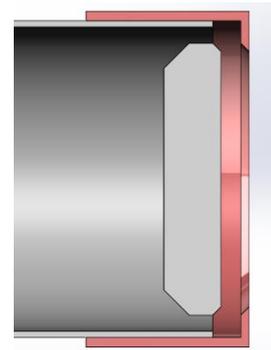


Figure 34: System open

5.9.4 Preliminary Pros and Cons

Pros	Cons
Regulates flow	Large
Dissipates energy	Installing the rock blocks
Easy installation of valve	Affects surroundings
Cheap	

5.10 Rotary cylinder

5.10.1 Introduction

This concept is similar in shape as “movable pipe 2” but operates in another way. The control mechanism is based on rotation, making the movement in the system minimal.

5.10.2 Concept

As with several of the concept already mentioned, the rotary cylinder is based on energy dissipation by inducing turbulent flow. The water flows into the rotary cylinder from the outside and crashes in the middle. The rotary cylinder has the same working principles as “moveable pipe 2”.

The way the water is regulated is using a sleeve on the outside of the perforated tube. This sleeve will only allow a certain amount of the holes to be exposed, meaning that only the exposed holes will be open and let water through. This sleeve is rotary, so turning it will cover or expose more holes. As this rotary mechanism is not working against any current, it will not require much energy or force to operate.

5.10.3 Model

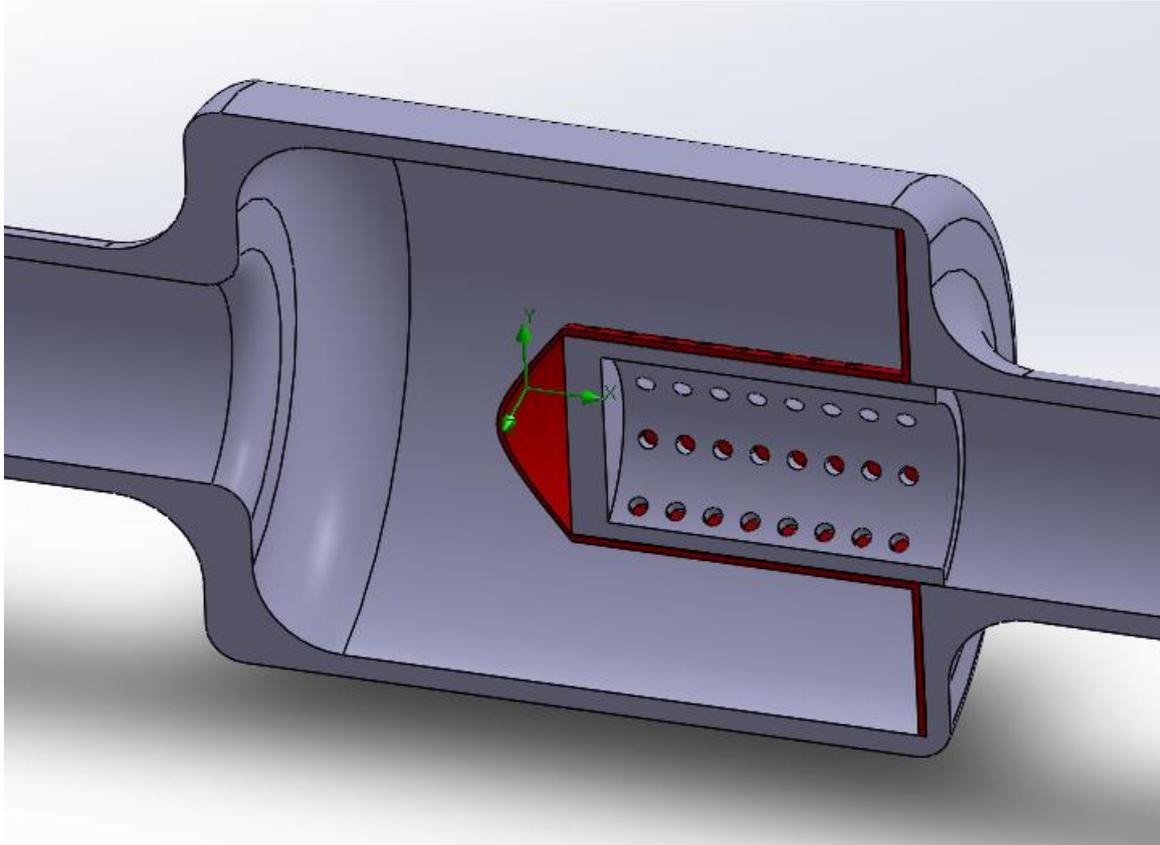


Figure 35: Cross sectional view of the rotary cylinder

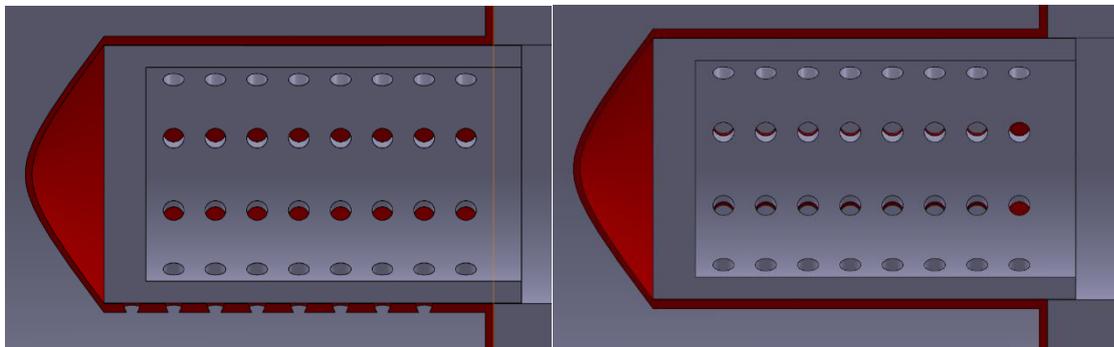


Figure 36: System closed

Figure 37: System open

5.10.4 Preliminary Pros and Cons

Pros	Cons
Cheap to operate	Custom parts
Regulates flow	Cavitation on perforated tube
Dissipates energy	Expensive

5.11 Maze

5.11.1 Introduction

This concept came at a request from Multiconsult. Creating a maze for the water to go through is something that exists and is in use today. It has yet to be used in a bypass system, Multiconsult therefore urged the group to make a design including a maze.

5.11.2 Concept

The idea is to have six paths that become narrower and narrower. These paths start at the edges of the pipe and end up in the center. At the end of the pipe, they meet and are blasted into each other. The dissipating factor here is both the narrowing of the paths as well as the turbulence that is produced in the middle.

Although it has some capabilities to regulate the flow, it is not able to completely control it. Meaning that it is not a shutoff valve and must either be redesigned or used in conjunction with another valve.

The flow is regulated by rotating a disc with holes in. the holes vary in size, which allows for different amounts of water to be let through.

5.11.3 Model

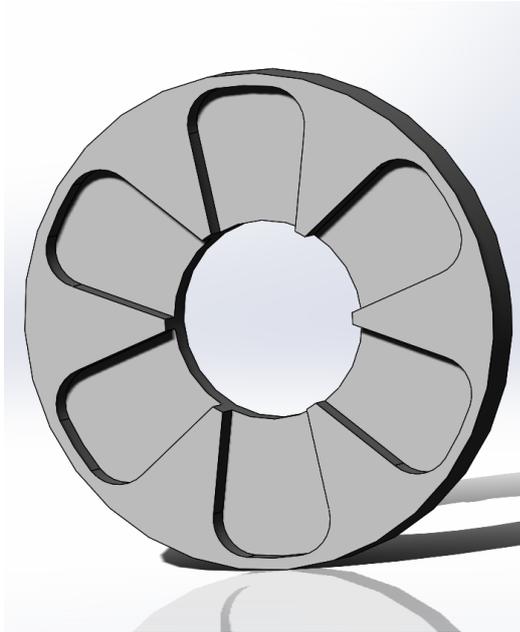


Figure 39: Flower pedal design

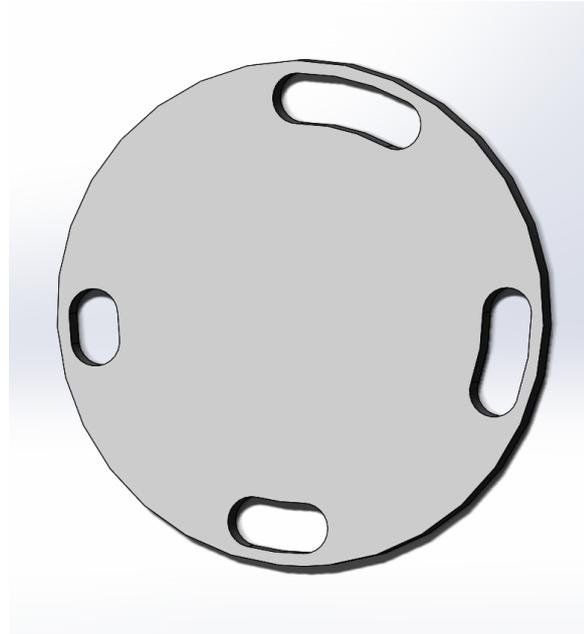


Figure 38: Rotary, flow controlling part of the maze concept

5.11.4 Pros and Cons

Pros	Cons
Dissipates energy	Doesn't regulate flow completely
Simple	Massive parts

6 Pugh matrix

The Pugh-matrix was developed by Stuart Pugh as a tool to compare alternative designs to an established reference to determine the best possible design. The Pugh-matrix has many advantages, but one should be aware of that it can be misused. The misuse can happen when there is a lack of data to apply to the criteria. It should also be noted that the matrix is used based on the project group's perceptions. This means that it is easy to be fooled into choosing a concept based on the wrong interpretation of the data.

Each stage of the process requires discussion, which concept alternatives to consider, which criteria to base the matrix on and rating the concepts based on the criteria (Bailey & Lee, 2016, p. 32). These discussions will lead to a deeper understanding of each concept.

In this case, the group will do technical research into each concept based on the criteria described in *Chapter 0*. It is important that the criteria we choose are relevant to satisfy the stakeholders, and that they are measurable and comparable in the different concepts that we need to choose from.

6.1 Structure of our Pugh matrix

This subchapter will briefly describe the structure of our Pugh matrix and how we are calculating the final score.

Concepts Criteria	Priority (1-6)	Concept 1	Concept 2	Concept 3
		Bucket	Movable pipe 1	Jet valve
Cavitation				
Weight & Size				
Complexity				
impact on surroundings				
Control mechanism				
Production method				
Flow characteristic				
Total score				

Table 11: Pugh matrix example

Criteria

The criteria chosen for the Pugh-matrix can be found in the left column. The criteria serve as the foundation for the selection of the concepts. Each of them will be describe more in detailed in the subchapter "0 Criteria"

Priority

The blue column displays the priority the criterion has. Some criteria are more important than others and should be taken into account in the Pugh-matrix. For instance, the energy dissipation criterion will have a higher priority than impact on surroundings. The priority is multiplied with the criterion score.

Concepts

The orange section displays the concepts that will be compared. In Table 11, only the three first concepts are listed to save some space. The full matrix can be found in Table 14. Each of the concept has an individual number and a temporary name. The score from the criteria will be listed under each concept in the white area.

Total Score

When adding up all the criteria with the priority we get the total score for each of the concepts. When selecting a concept, the total score will be compared. The total score is given by the following equation:

$$(Criteria_{Cavitation} * Priority_{Cavitation}) + (Criteria_{Complexity} * Priority_{Complexity}) + \dots = Total\ Score$$

6.2 Scaling

Each concept will be rated in each criteria on a scale from 1 to 6. Underneath is a table describing the different values.

Value	Level	Description
6	Excellent	An excellent performance, clearly outstanding. The concept could not have performed better in this criterion.
5	Very good	A very good performance. The criterion is being met and there is very little room for improvement.
4	Good	The concept fulfills the criterion.
3	Satisfactory	The concept fulfills the criterion but has major room for improvements.
2	Sufficient	The criterion is barely being met.
1	Fail	The criterion is not being met at all.

Table 12: Scores

6.3 Criteria

This chapter contains an in-depth explanation of the criteria, and how to measure them. These criteria serve as the foundation for the selection process. The chapter will also discuss the priority scale for each of the criteria.

The group have chosen to not have a separate criterion for the cost of the valve. This is because the cost is dependent on several criteria that already is included; complexity, Weight & Size and production method. In analyzing these three, the group is confident that the scores they provide will give a good representation of the cost.

6.3.1 Complexity

Complexity can be defined as how many parts that is involved in a system. To analyze this criterion, the group looked at how many parts, how many moving parts, the assembly of the parts is in each concept, how easy it is to service and how accessible it is once installed.

The full analysis for this criterion can be found in the "*Criterion Analysis-Complexity*" document (see Appendix H).

6.3.2 Weight & Size

To analyze the Weight & Size of the different concept the group used SolidWorks. The measurement tool was used to record the maximum length, height, and width of the models, multiplied them together. This volume was used in the analysis. The massiveness of the valve was also considered, I.E. how many and how large the massive parts are.

The analysis for this criterion can be found in "*Criterion Analysis-Weight and size*" document (see Appendix F).

6.3.3 Production method

The production method has a huge impact on the cost of the valve. The analysis will focus on the cheapest way the parts in the concept can be produced, and if it is at all possible.

The analysis of this criterion can be found in the document the "*Criterion Analysis-Production Method*" document (see Appendix G).

6.3.4 Cavitation

SolidWorks' flow analysis is used to evaluate this criterion. The group used data from the stakeholder requirements as parameters to conduct the flow analysis. "Volume fraction of Vapor" is a good measurement for the rate and location of cavitation. This parameter describes where in the model water is converted to vapor, and thus where cavitation is occurring. The concepts are rated on location and degree of cavitation.

The full analysis can be found in the "*Criterion Analysis-Cavitation*" document (see Appendix H).

6.3.5 Control mechanism

One of the requirements is that our solution must be able to control the flow rate. This is done by having a control mechanism in the valve. This criterion assesses the complexity of the mechanism and the sealing. The ease of implementation is also considered.

The full analysis can be found in the “*Criterion Analysis-Control mechanism*” document (see **Appendix I**).

6.3.6 Flow characteristic

How the flow behaves through the system can have a huge impact on the operation. A requirement from our stakeholder states that the system must have a predictable flow characteristic. A predictable flow characteristic means the relation between the amount of water passing by the system and the opening grade should be clear. SolidWorks flow simulation will be used to analyze the criterion.

The full analysis can be found in the “*Criterion Analysis-Flow characteristic*” document (see **Appendix J**).

6.4 Priority scale

There are some criteria that are more important, and to properly display this in the Pugh-matrix there is a need for a weighted diagram. Some criteria will “count” more than others because they are more important. Each criterion will be weighted with a number between 1 and 6, where 6 count the most and 1 the least.

The priority scale is a crucial part of the Pugh matrix. Small changes to the scale will have a ripple effect on the entire matrix. By that reason, we will consult with our stakeholder and have an evaluation after the last result.

Criteria	Weight
Cavitation	6
Weight & Size	3
Complexity	4
Control mechanism	4
Production method	4
Flow characteristic	5

Table 13: Priority scale



Criteria	Concepts									
	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6	Concept 7	Concept 8	Concept 9	Concept 10
	Priority (1-6)									
Cavitation	6	2	3	4	5	6	7	8	9	10
Weight & Size	3	5,5	4,5	3,5	4	6	5,5	2,5	4,5	4
Complexity	4	3	3	2,2	4,2	2	2,8	4	4,2	4,4
Control mechanism	4	4,5	5,7	2,4	3,8	4,5	5,6	4,7	5,8	4,9
Production method	4	5,2	2,9	1	4,4	4,8	3,5	5,4	1,6	6
Flow characteristic	5	6	5	3	4	1	5	2	3	5
Total score	104,9	109,3	102,9	80,9	99,6	74,2	125,1	85,9	80,9	122,2

Table 14: Pugh-matrix with results

6.6 Evaluation

The initial scores presented in *Chapter 6.6* confirm that concept 7 “the movable pipe 3” and concept 10 “the maze” are the concepts with the highest potential. The difference in score between them is very small. The Pugh-matrix can easily be misused and there are several measures that has been done to avoid this. One measure that has not yet been done is to evaluate the priority scale. Small changes in the scale can have a huge impact on the final scores. The next subchapter will therefore give an insight in how small changes in the priority scale can affect the score. The group will also have a risk assessment concerning the two leading concepts. How well develop the two concepts are and the risk regarding the analyses will be evaluated. After these two evaluations, the final concept will be presented.

6.7 Evaluating the priority scale in consideration to scalability

The evaluation of the priority scale is done to test if the systems can work under different circumstances and if they are suited to different kinds of facilities. The group made two different priority-scaling alternatives. The assignment presented by Multiconsult states that the system should be scalable. This means that it must work in big facilities as well as smaller ones.

6.7.1 Alternative 1

For a bigger facility, the main concern is the flow characteristics and cavitation of the system. In a facility such as this, the money spent on a bypass-system is representing such a small percentage of the total cost of the facility, that the cost of the bypass system is more or less neglectable. For this reason, no expense is cut. The facility wants the optimal system flawless flow characteristics and cavitation.

Criteria	Weight
Cavitation	6
Weight & Size	1
Complexity	2
Control mechanism	3
Production method	3
Flow characteristics	6

Table 15: Priority scale alternative for a bigger facility

Concepts Criteria	Priority (1-6)	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6	Concept 7	Concept 8	Concept 9	Concept 10
		Bucket	Movable pipe 1	Jet valve	movable pipe 2	Energy dissipating box	Plug	Movable pipe 3	Rock block	Rotary cylinder	Maze
Cavitation	6	6	2	3	5,5	3	1	6	2	1	4
Weight & Size	1	1,5	5,5	4,5	3,5	4	6	5,5	2,5	4,5	4
Complexity	2	2,4	3	3	2,2	4,2	2	2,8	4	4,2	4,4
Control mechanism	3	5,6	4,5	5,7	2,4	3,8	4,5	5,6	4,7	5,8	4,9
Production method	3	3,1	5,2	2,9	1	4,4	4,8	3,5	5,4	1,6	6
Flow characteristic	6	4	6	5	3	4	1	5	2	3	5
Total score		92,4	88,6	84,3	69,1	79	49,9	104,4	64,8	59,1	99,5

Table 16: Pugh-matrix where the priority has been scaled for a larger sized facility

6.7.1.1 Alternative 2

For a very small facility, the price will play a huge part. In facilities like this, even though it is still important, the cavitation might not be as important as in a bigger facility because of the lower operating pressures. A facility like this will operate with minimum amount of service. It is therefore important that the system can work for as long as possible without supervision. For these reasons, the cost must be low, and the system should be as simple as possible.

Criteria	Weight
Cavitation	4
Weight & Size	4
Complexity	5
Control mechanism	3
Production method	3
Flow characteristics	5

Table 17: Priority scale alternative for a smaller facility

Concepts Criteria	Priority (1-6)	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6	Concept 7	Concept 8	Concept 9	Concept 10
		Bucket	Movable pipe 1	Jet valve	movable pipe 2	Energy dissipating box	Plug	Movable pipe 3	Rock block	Rotary cylinder	Maze
Cavitation	4	6	2	3	5,5	3	1	6	2	1	4
Weight & Size	4	1,5	5,5	4,5	3,5	4	6	5,5	2,5	4,5	4
Complexity	5	2,4	3	3	2,2	4,2	2	2,8	4	4,2	4,4
Control mechanism	3	5,6	4,5	5,7	2,4	3,8	4,5	5,6	4,7	5,8	4,9
Production method	3	3,1	5,2	2,9	1	4,4	4,8	3,5	5,4	1,6	6
Flow characteristic	5	4	6	5	3	4	1	5	2	3	5
Total score		88,1	104,1	95,8	72,2	93,6	70,9	112,3	78,3	80,2	111,7

Table 18: Pugh-matrix where the priority is scaled for a bigger facility

6.7.1.2 Conclusion

In both alternatives, it is still concept 7 and 10 that are leading, and the difference in scores is very low. The priority alternatives have not provided a clear winner.

6.8 Risk assessment

Seeing as the scores of concepts 7 and 10 are equal in the Pugh-matrixes, they are both seen as winners. Which concept will be chosen will therefore have to be decided in another way. A concern the group has about the two concepts is how well developed they are. Even though both are in an early stage of the development-phase, concept 7 has come considerably further in this phase than its counterpart. This can both be a good thing and a bad thing. One might say that concept 10 has a greater potential, seeing as it hasn't been developed as much yet. This might be true, but it also includes a bigger risk. The analyses the group has done will be more accurate on concept 7 compared to concept 10. Meaning that when concept 10 is developed further its score might decrease. Concept 7 has come to the stage where it will not be altered in any major way further, its therefore the "safer" alternative of the two.

7 “Final concept”

The concept the group has chosen to develop further is the movable pipe 3, hereby called Movable pipe. The risk assessment concluded the concept was the safer alternative of the two. The movable pipe shows great potential regarding cavitation, but the complexity of the valve needs to be evaluated. In the next iteration, C3, optimizing the concept and creating a finalized product will be the focus.

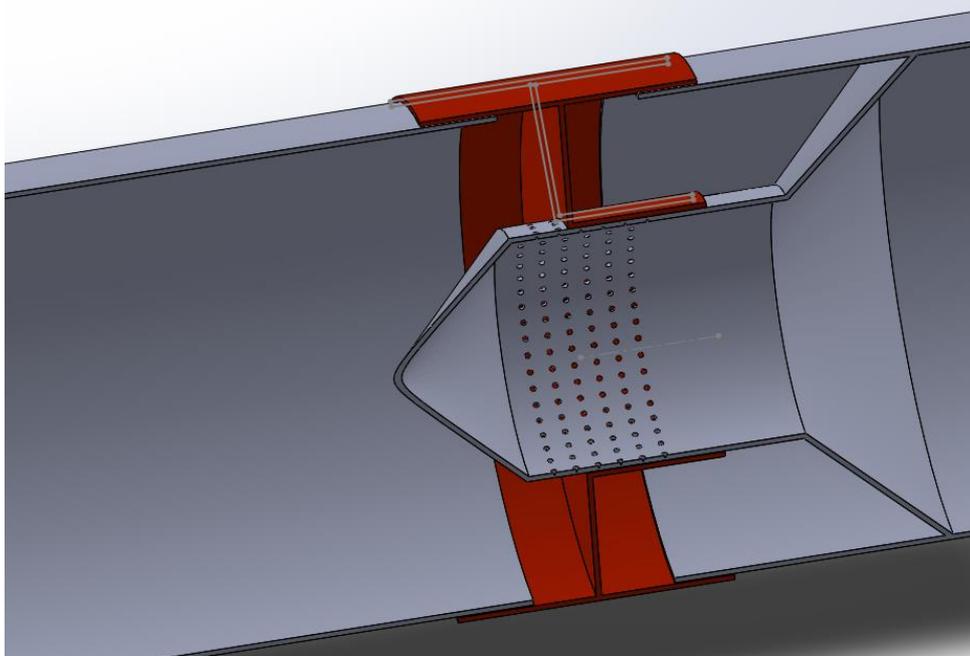


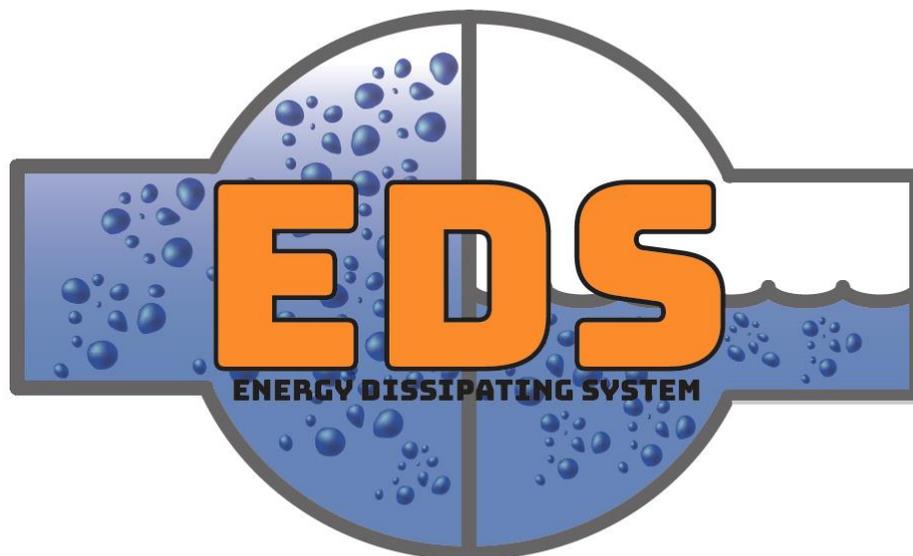
Figure 40: The winning concept, Movable Pipe.

Multiconsult

Design of bypass valve

Technical document: Design

22.05.2018



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Abstract

Background: The design document presents design choices and changes made to the system through each increment.

Method: The different design choices were discussed in-depth in relation with both pressure class PN40 and ASME B16.34. Basic calculations were made based on these pressure classes and the input parameters from the system requirements.

Results: The valve ends will be flanged. A combination of O-ring and chevron-sealing is used. The valve body thickness must be above 21.4mm and the diameter must be above 618mm. The design is based on these parameters and results from FEM analysis. The design for the bypass valve evolved over the course of six increments.

Document history

Version	Date	Author	Description
0.00	17.04.18	OO	<ul style="list-style-type: none">• Created the document
0.01	19.04.18	MH	<ul style="list-style-type: none">• Started design history chapter
0.02	24.04.18	MH	<ul style="list-style-type: none">• Added sub-chapters to design history
0.03	04.05.18	MH	<ul style="list-style-type: none">• Added sub-chapters to design history
0.04	11.05.18	MH	<ul style="list-style-type: none">• Finalized design history text• Added figure texts
0.05	15.05.18	JS	<ul style="list-style-type: none">• Proofread
0.06	15.05.18	LH	<ul style="list-style-type: none">• Added sealing description and choice
1.00	19.05.18	LH, JS, MH	<ul style="list-style-type: none">• Proofreading and finalizing for publishing

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1 Introduction

During the inception phase of the project, critical thinking was thrown out the window. This led to multiple concepts, whereas the chosen concept was one of them. Although this way of working certainly led to some untraditional and new-thinking concepts, the concepts were far from finished.

The chosen concept had to be further developed and refined to perform the tasks properly. Throughout this iteration of the project, the C3 iteration, development and optimization of the concept has been the focus. This means altering the concept so that it will perform the tasks as good as possible.

The changes made are products of the results from various analyses. The input given by the analyses will determine the dimensions etc. for the system, but it is up to the group to make the correct design. A major part of designing a system like this is using common knowledge and critical thinking to see whether a system will work or not. To get a better overview over the changes made, and to promote a better progress, an incremental approach was used.

2 Design choices

The chapter will present general design choices. These design choice serves as a foundation for further design and have an impact on the theoretical calculations given in the next chapter.

2.1 Pressure rating

When developing the concept there will be necessary to use some kind of standards. Selection of materials and some general dimension will be established with the use of tables provided by standards. The standards use several types of classifications, for example, ISO standards use the pressure nominal (PN) and ANSI uses a pressure class. PN is given in bar and the pressure class is given in psi. The group will base the design on using the pressure nominal system provided by ISO. The main reason is that ISO provides the widest pressure range and conversion over to other classifications like ANSI or API. Guidelines from NVE also refers to PN values. Our requirement is to design a system that can operate in a pressure up to 30 bar. From standard PN classes, this is between PN25 and PN40. After conversations with our stakeholder, Multiconsult, the group decided to choose PN40. The reason is that the pressure class will cover most of hydropower plants even though it is higher than the given pressure. If other standards are to be used the conversion will be from PN40 to the given class.

2.2 Valve end connection

Design choices that can be completed at an early stage is the selection of the end connection. End connections are associated with the pipework and the application for the hydropower plant. The selection is also dependent on the temperature and pressure of the fluid and how often the valve is dismantled from the line. The end connection can be divided into 3 groups: flanged, threaded and welded end connections. To decide which one of these types is the most appropriate choice for the application, the group will briefly present each alternative and the common use for them. It should be mentioned that there are several configurations in each of the groups as well.

Threaded end connection

Threaded end connection is a connection where the pipe and valve get screwed together (Stoneleigh, 2018). The screw pattern is located around the outer or the inner side of the valve. The threads can either be male or female connections, but the female connection is the most common. Threaded end connections are usually used for pipe sizes under 150mm. The connection is often used for bronze valves and to a lesser extent for iron and steel valves.



Figure 41: Threaded end valve connection (Jomar, 2018)

Flanged end connection

A valve with a flanged end is connected by merging the valve flange and pipe flange together, these flanges are then bolted together (Welsford, 2016). These types of connections are known to be easy to install and remove from the line. A gasket between the facings will also be required to ensure a tight seal. Bronze, iron and steel valves are normally designed with a plain/flat facing, but there is also possible to get a male/female configuration. Flanged valve end connection is used on a wide range of applications, usually made for sizes over 15mm.



Figure 42: Flanged end valve connection (Jomar, 2018)

Welded end connection

These types of valves are connected with the pipeline by welding (Stoneleigh, 2018). One reason for welding the valve and pipe together is to minimize the risk of leakage. Welded connections are often a more cost-efficient choice, but the downside is that the joining is permanent and will require a lot of work to disassemble. There are two commonly used welded connections; socket- and butt-welded ends. Socket weld is used for valve sizes under 50mm and butt welded is usually used for sizes over 50mm.



Figure 43: Welded end valve connection (Haitima Corporation, 2004)

2.2.1 End connection choice

With the general information of the end connection, there is one that shows the most potential. The Flanged end connection will be the most applicable choice, for two main reasons. The first is that the flanged end connection can withstand the operating pressure and has the opportunity to be used in a wide range of operating pressures. This ensures scalability. The second and most important reason is that valves with flanged end connections can easily be removed and installed.

2.3 Sealing

The bypass valve will operate under a pressure equal to PN40 (40 bar), and it is important that it has sufficient sealing to prevent leakage (Nesbitt, 2011, p. 264). There are numerous sealing methods and materials. To describe some of the ways to seal a valve a stem/spindle operated valve will be used, shown in *Figure 44*. The majority of sealing in this type of valve is achieved by compressing a soft flexible material between the stem/spindle and the outer material. The selected material should be softer than the valve material to reduce wear. It should also be flexible to fill the cavities in the material to further improve the sealing. The sealing should also be protected from the environment, as dust and other particles will cause the sealing to wear and perform poorer. It should be noted that the stem/spindle is only one of the potential leaks and other openings and pipe connections also need sealing. One of the potential dangers of insufficient sealing is that the fluid can “flash” into vapor due to the large pressure difference. This will cause “wire drawing”, a small fluid flow through the sealing that will erode it over time. This results in very short seal life and potential damage to the control mechanism in the valve. One thing that must be considered when designing or choosing the sealing method is pressure and temperature spikes in the system. The sealing must withstand sudden changes to the pressure and temperature.



Figure 44: Stem/spindle operated valve (Nesbitt, 2011, p. 270)

2.3.1 Sealing types

As previously mentioned, there are several ways to seal, and with many different materials. This chapter will go more in-depth in some of the ways and materials that are used. In short, there are three different sealings: single, double and custom sealings.

2.3.1.1 Single sealing

The stem sealing can be done extremely simply with an O-ring that revolves around the stem shown in *Figure 45*. The compression of the O-ring is controlled with the size of the groove it is seated in. According to *Brian Nesbitt (2011)*, wear and corrosion results in poorer sealing performance (Nesbitt, 2011, p. 264). *Figure 46* shows another method of using rings as sealing. Thin filled layers are fitted between the sealing rings to increase the packing stiffness. The rings shown are solid and can be PTFE rings filled with glass or carbon fiber.

The method previously described uses pre-compression to achieve optimal sealing capability, but this compression can also be achieved by using a spring inside the sealing. Combined with chevron shaped rings will increase the sealing capability. The sealing capability of the chevrons will increase with the pressure from the fluid under them. *Figure 48* shows a typical sealing assembly with the same sealing as in *Figure 47*.

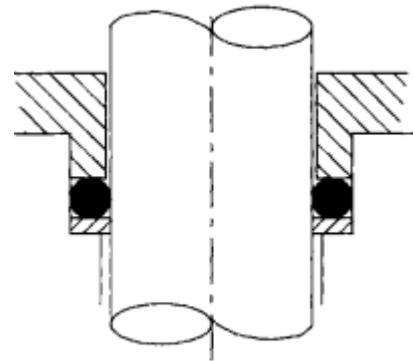


Figure 45: Cross sectional figure of a stem sealing. The O-ring represented by the black circles prevent leakage from inside the valve by sealing the stem (cylinder in the middle) (Nesbitt, 2011, p. 265)

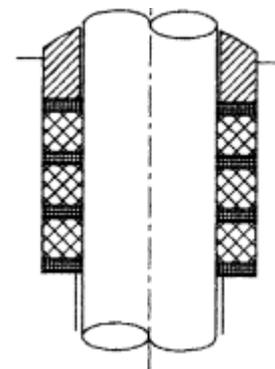


Figure 46: Soft packing represented by the three squares with thinner, stiffening spacers fitted between them (Nesbitt, 2011, p. 266)

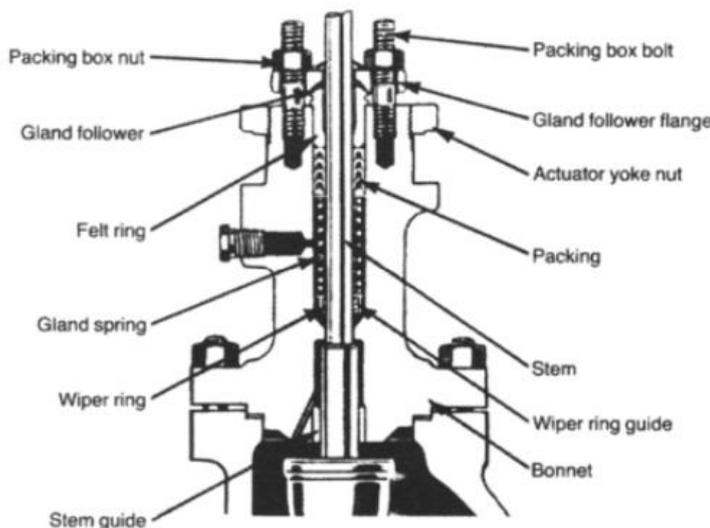


Figure 48: Typical valve assembly with spring-loaded chevron packing (Nesbitt, 2011, p. 268)

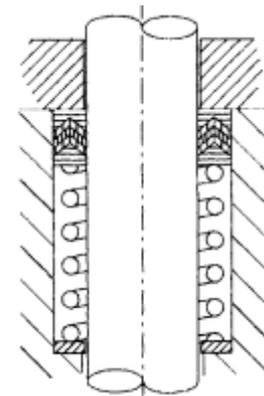


Figure 47: Helical spring-loaded chevron packing. The chevrons at the top will seal and the helical spring going around the stem "live load" the pack (Nesbitt, 2011, p. 267)

2.3.1.2 Double seals

Double seals are used where hazardous fluids are handled or when external lubrication is used. In *Figure 49*, a double O-ring design is used on the stem of a butterfly-valve. The connection shown to the right of the stem can be used for lubrication or leakage monitoring. The second sealing is often used as a backup to the first one. *Figure 50* shows a double spring-loaded chevron sealing, where the connection to the right serves the same purpose as in *Figure 49*. In terms of the bypass valve double sealing can be used to stop abrasives and debris from entering the main sealing.

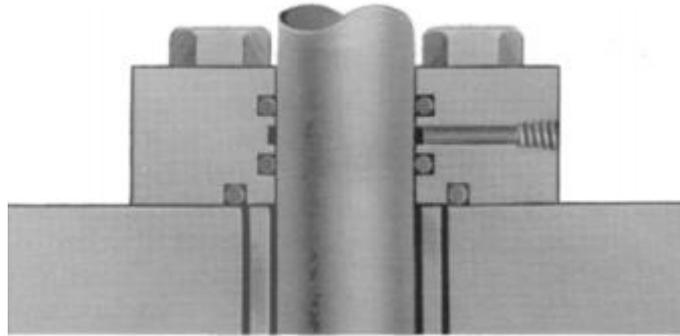


Figure 49: Double O-ring sealing (Nesbitt, 2011, p. 268)

2.3.1.3 Special design

Extreme temperature, both high and low can create sealing problems (Nesbitt, 2011, p. 269). The metal body has no problem withstanding the temperatures, but plastic and elastomer sealing are limited to maximum temperatures around 260 °C. This calls for a special design to either the valve or the sealing packing. One example is to increase the stem length shown in *Figure 44*, and use the ambient temperature as help to cool the fluid before it reaches the sealing.

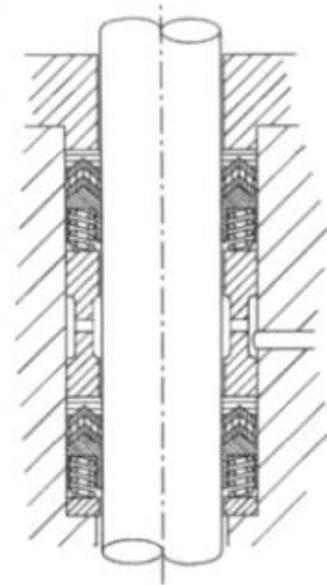


Figure 50: Double spring-loaded chevron seals (Nesbitt, 2011, p. 269)

2.3.2 The sealing choice

There are two different sealing types that will be used. Inside on the valve trim two O-rings will be used. To seal at the control mechanism a chevron (u-cup) will be used.

3 Theoretical calculations

Calculations are done to find the minimum pipe diameter, to achieve the maximum flow rate, and to find the minimum required wall thickness for the PN40 pressure class. These values are a starting point for the design, the FEM analysis and the material choice. It should be noted that these values are the minimum to fulfill the requirements and they will most likely be increased slightly.

3.1 Minimum Pipe diameter

The minimum pipe diameter can be calculated using the equation for the volumetric flow by solving with respect to the diameter. From requirement RQ-1, the volume flow can be selected. RQ-1 states that the system must operate in with a volume flow between 0.5 and 3 cubic meters per second. To calculate the minimum allowed pipe diameter the group uses 3 cubic meters per second. The reason why the highest volume flow rate is selected is because a lower volume flow rate would have given a smaller pipe diameter. This could result in a pipe that may not be able to withstand the operating forces.

$$\text{Pipe diameter: } D = \sqrt{\frac{4Q}{\pi v}}$$

$$\text{Where: } Q = \text{Volumetric flow } [m^3/s]$$

$$v = \text{velocity } [m/s]$$

$$D = \text{diameter } [m]$$

Using values provided from RQ-2 and RQ-5 we get:

$$D = \sqrt{\frac{4Q}{\pi v}} = \sqrt{\frac{4 * 3 m^3/s}{\pi * 10 m/s}} = 0.618m = \mathbf{618mm}$$

The inner pipe diameter must be over 618mm or more to satisfy the given requirements.

3.2 Determining the valve body wall thickness Using ASME B16.34

Reference to the standard: (The American Society of Mechanical Engineers, 2004)

ASME is an abbreviation for “The American society of mechanical engineer”. B16.34 is standards concerning valves that has flanged, threaded or welded ends. Values from the standard will be provided from the 2004 edition and not the newest 2013 edition because the 2004 is open source.

The standard will provide a minimum wall thickness, t_m , but in order to determine the value there are some steps to go through. First step is to choose a material, which is provided from the material selection (*see Technical document: Material*). The selected material for the valve body is carbon steel P355NH. This is a European carbon steel quality and for these calculations an American standard is required. The equivalent quality to the European P355NH is the American A537. (MEsteel, 2018). Next, the pressure class need to be defined by using a pressure – temp table and last the minimum valve body wall thickness can be selected from the pressure – diameter table using the applicable pressure class. These steps will be described more in detail in the following chapters.

Determine the pressure class with the “pressure-temperature”-table:

From “**pressure rating**”-chapter the pressure class PN40 was selected. The ASME is operating with another pressure class than PN. By using the “pressure-temperature”-table the group can find the ASME class that relates to PN40. The operating temperature needs also to be selected. Seeing as the system is operating in a normal environment the chance of temperature to rise over 38°C and under -29°C is minimal.

There are also two table classes to choose from: “A – Standard class” and “B – Special class”. Briefly explained, class A addresses valves with flanged ends and B addresses valves with threaded and welded ends. From chapter 2.2 the flanged end was selected which means class A will be used.

A – Standard Class								
Temperature, °C	Working Pressures by Class, bar							
	150	300	600	900	1500	2500	4500	
-29 to 38	19.6	40 bar	51.1	102.1	153.2	255.3	425.5	765.9
50	19.2	50.1	100.2	150.4	250.6	417.7	751.9	
100	17.7	46.6	93.2	139.8	233.0	388.3	699.0	
150	15.8	45.1	90.2	135.2	225.4	375.6	676.1	
200	13.8	43.8	87.6	131.4	219.0	365.0	657.0	
250	12.1	41.9	83.9	125.8	209.7	349.5	629.1	
300	10.2	39.8	79.6	119.5	199.1	331.8	597.3	
325	9.3	38.7	77.4	116.1	193.6	322.6	580.7	

Figure 51: ASME B16.34 A-standard class

From the table above, the pressure class can be located to be between 150 psi and 300 psi. Linear interpolation can then be used to determine a more specific value, which gives us:

$$\text{Linear interpolation formula: } y_2 = \frac{(x_2 - x_1)(y_3 - y_1)}{(x_3 - x_1)} + y_1$$

$$\text{Pressure class} = \frac{(40 - 19.6)(300 - 150)}{(51.1 - 19.5)} + 150 = 246.83 \text{ psi} \approx \mathbf{247 \text{ psi}}$$

Determine the minimum wall thickness with the “pressure-diameter”-table

Now that the pressure class is calculated the minimum body wall thickness, t_m , can be found.

Table 3-A Valve Body Minimum Wall Thickness, t_m , mm (Cont'd)

Inside Dia. d , mm [Note (1)]	Minimum Wall Thickness – t_m , mm							
	Class 150	247	Class 300	Class 600	Class 900	Class 1500	Class 2500	Class 4500
320	9.9		15.0	24.2	36.0	61.6	111.6	253.7
330	10.1		15.3	24.9	37.0	63.4	115.0	261.6
340	10.2		15.7	25.6	38.1	65.2	118.4	269.4
350	10.4		16.0	26.3	39.1	67.1	121.9	277.2
360	10.6		16.3	26.9	40.2	68.9	125.3	285.1
370	10.7		16.7	27.6	41.2	70.8	128.7	292.9
380	10.9		17.0	28.3	42.2	72.6	132.1	300.8
390	11.1		17.3	29.0	43.3	74.5	135.5	308.6
400	11.2		17.7	29.6	44.3	76.3	138.9	316.5
410	11.4		18.0	30.3	45.4	78.2	142.3	324.3
420	11.5		18.3	31.0	46.4	80.0	145.7	332.2
430	11.7		18.7	31.7	47.5	81.8	149.1	340.0
440	11.9		19.0	32.4	48.5	83.7	152.5	347.9
450	12.0		19.4	33.0	49.6	85.5	155.9	355.7
460	12.2		19.7	33.7	50.6	87.4	159.4	363.6
470	12.4		20.0	34.4	51.7	89.2	162.8	371.4
480	12.5		20.4	35.1	52.1	91.1	166.2	379.3
490	12.7		20.7	35.7	53.7	92.9	169.6	387.1
500	12.9		21.0	36.4	54.8	94.8	173.0	395.0
510	13.0		21.4	37.1	55.8	96.6	176.4	402.8
520	13.2		21.7	37.8	56.9	98.4	179.8	410.7
530	13.3		22.0	38.5	57.9	100.3	183.2	418.5
540	13.5		22.4	39.1	59.0	102.1	186.6	426.4
550	13.7		22.7	39.8	60.0	104.0	190.0	434.2
560	13.8		23.0	40.5	61.1	105.8	193.4	442.1
570	14.0		23.4	41.2	62.1	107.7	196.9	449.9
580	14.2		23.7	41.8	63.1	109.5	200.3	457.8
590	14.3		24.0	42.5	64.2	111.4	203.7	465.6
600	14.5		24.4	43.2	65.2	113.2	207.1	473.5
610	14.6		24.7	43.9	66.3	115.0	210.5	481.3
620	14.8	25.0		44.6	67.3	116.9	213.9	489.2
630	15.0	25.4		45.2	68.4	118.7	217.3	497.0
640	15.1	25.7		45.9	69.4	120.6	220.7	504.9
650	15.3	26.0		46.6	70.5	122.4	224.1	512.7
660	15.5	26.4		47.3	71.5	124.3	227.5	520.6

Figure 52: ASME B16.34 Table 3-A to find the minimum valve body thickness



Using the known pressure class and the inner diameter determined from “*inner diameter calc*”, which provided an inner diameter of $d=618\text{mm}$, the thickness can be located to be between class 150 and 300. Using again linear interpolation the minimum wall thickness can be found:

$$t_m = \frac{(247 - 150)(25 - 14.8)}{(300 - 150)} + 14.8 = \mathbf{21.4\text{ mm}}$$

By using the ASME B16.34 the minimum body wall thickness is recommended to be at least 21.4 mm. The material strength will be tested in a later FEM-analysis to insure the thickness is appropriate (*see Technical document: FEM*).

4 Design history

Throughout the design process, there has been multiple changes. These changes have been made by the group in order to develop a better performing system, according to the requirements set.

The group has used an incremental approach when designing the system. By working like this, the system is constantly changing and improving. This means that the group constantly has to make new tests and analyses to make sure that the system will work. Another aspect of the design process is common knowledge. Multiple choices have been made without the need of technical analyses. As engineers and designers of a system, this is a vital attribute. To be able to see if a system will work or not, to spot problems in a system and to find solutions for it.

By having a system in constant change, multiple analyses have to be made. This is to ensure that the system can withstand the pressure it experiences, as well as checking of the flow characteristics change. If the changes made to the design weakens the structural integrity of the system, measures must be taken to counteract these problems. This can either result in further design changes, or simply a change in dimensioning.

4.1 Initial concept

The concept developed in the concept-phase is based on keeping the moving mechanism on the outside of the system. Another main point for the system is using standardized parts. This means using parts that already has been manufactured. Resulting that the part won't have to be specifically made for the system. By using parts like this, the cost is drastically cut.

The system consists of several layers of piping. The outer pipe fits on the outside of the main water-pipeline. This pipe will be connected to the moving mechanism and the movable part on the inside of the main pipe. On the inside of the main pipe there is a smaller pipe with a perforated section on it. It is through these holes in the perforated section that the water will flow, and the energy will be dissipated. A certain amount of the holes will be covered by the movable pipe to allow for a certain amount of water to be let through. Before reaching this section of the system, the water will be split by a cone in front of the perforated pipe.

As this is simply a first draft of the system, there are still multiple vital pieces missing for it to fully work. Sealings, connections, gliding blocks etc, just to mention a few.

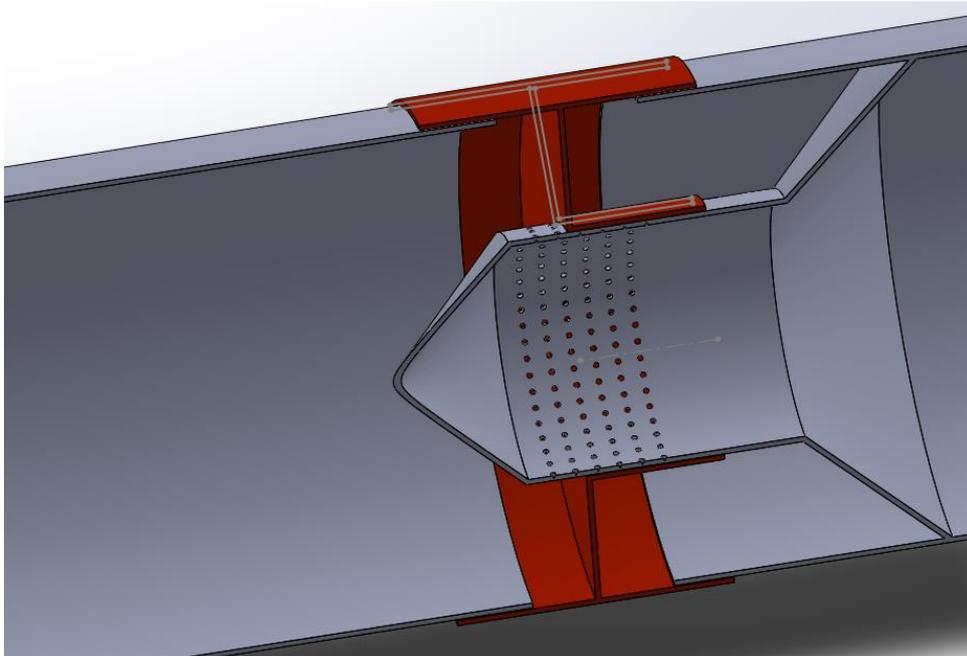


Figure 53 first draft of the system. Increment 1

4.2 First increment

In this increment of the system, the main pieces have been put in place. This is the first full configuration of the system, so there are still many uncertainties around the system. Whether it will work as intended or not. In this increment various sealings has been put in place. The sealings are a vital part in containing the water. For a system as complex as this, a multitude of sealings are needed, these are described further in the "Sealings"- chapter.

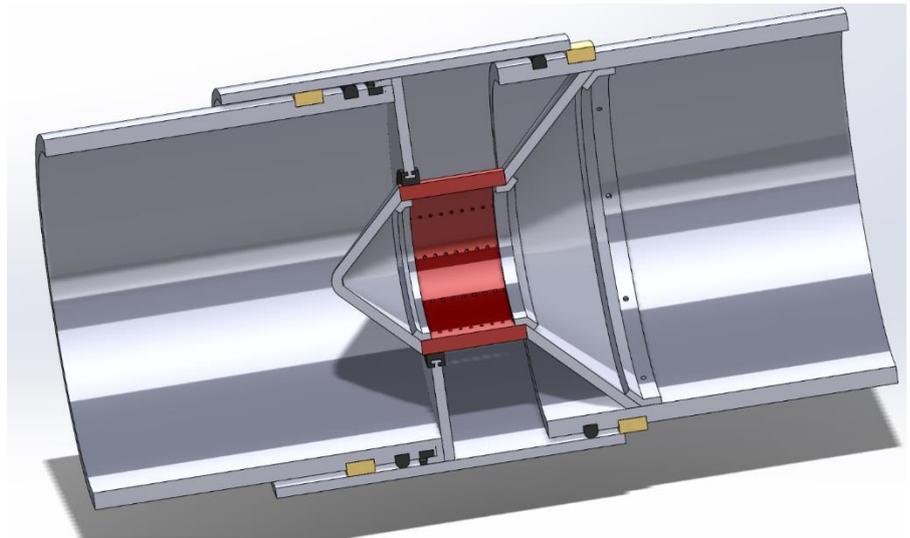


Figure 54 first model where all pieces are in place. Increment 1

For this increment, brackets and gliding blocks has also been added. The brackets are installed to hold everything in place, some of these brackets may be replaced by welds at later stages. The gliding blocks are installed to make the movable pipe glide smoother around the main pipe. At this increment it's important to notice the cone-shaped separating wall. The reason for this shape is to limit pressure-drops, thus decreasing risk of cavitation.

A problem with this configuration is that water will enter the cavity between movable wall and separating wall. The problem is that the water would not drain, meaning that it will stay there even when the system is not in use. These zones are highlighted in the Figure 55 . Having water stay like this for a prolonged period of time will severely affect the system, as the water erodes sealings as well as the valve body itself.

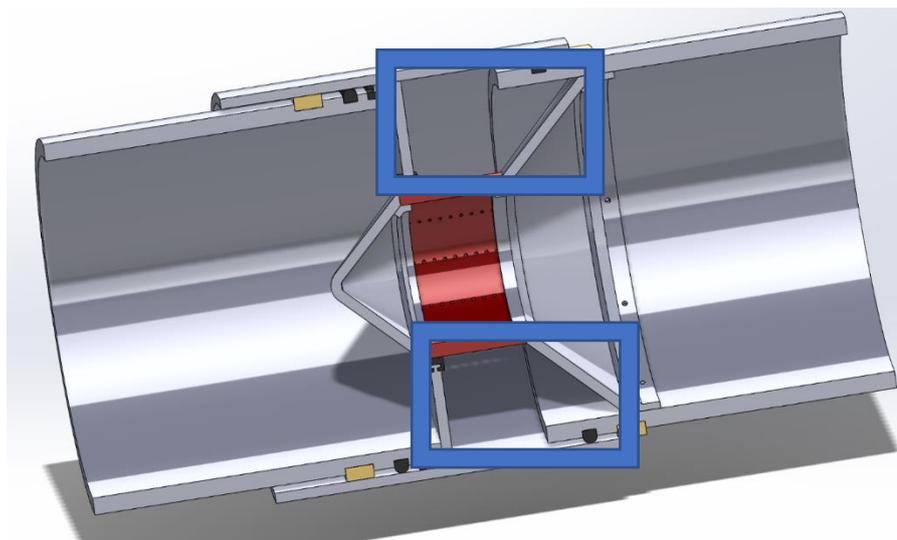


Figure 55 the blue squares illustrate where the water would be trapped.

4.3 Second increment

For this increment, the two main changes are the L-shaped foot and the vertical separating-wall. The L-foot is put in place to stop water from entering the cavity between the movable wall and the separating wall. By adding an L-foot that covers the holes that are not in use, will stop the water from entering the cavity. An added benefit of adding the L-foot is that the main sealing at the back of the system can be eliminated, as the sealing on the L-foot now will take care of the water.

To avoid vacuum or pressure-buildup between the moving wall and the separating wall, the gliding blocks on the back pipe have now been put in place horizontally, along the pipe.

The separating wall has now been placed vertically. The idea behind having an angled separating wall was to reduce the pressure drop in the area around the separating wall. After looking at the flow analysis and flow characteristics, it has been concluded that this is not necessary, and that a vertical separating wall will work. Due to lower production cost, easier installation and less space-consumption, a vertical separating wall is therefore chosen.

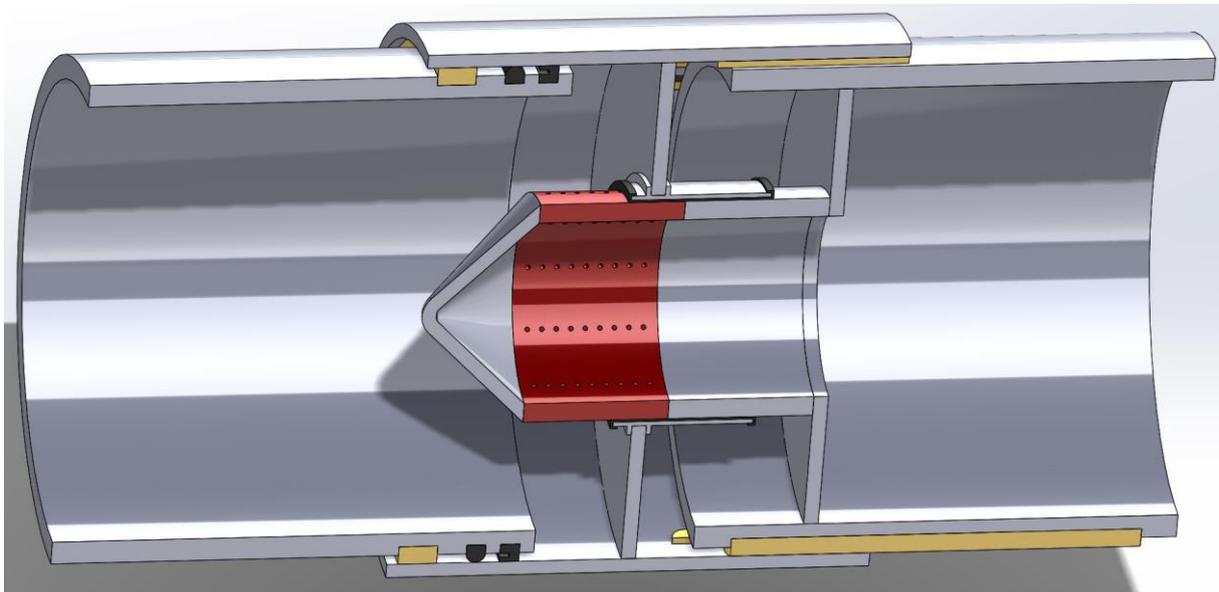


Figure 56 changed foot to make full sealing of holes, thus allowing for elimination of sealing on back part of the main pipe.

4.4 Third increment

Since it is crucial that the front and back pipe is inline, stiffeners are added. If the two pipe parts become off-centered, the sliding parts might jam, the sealing might leak, or even critical system failure might occur.

The best way to connect the two pipes is by gapping the shortage distance. To do this, the movable wall is trimmed to allow for stiffeners going through it. The stiffeners will help the system in keeping the correct shape. Although they will not completely stiffen the system, they will increase the stiffness compared to the previous solution. By trimming the separating walls, material is also saved.

To save material and allow for stiffeners between the two main pipes, the moving wall is now stripped down to the bare minimum. Now it doesn't serve as a wall separating the two sides, but rather an arm that moves the movable part. By opening up this wall, the sealings on the back pipe will have to be reintroduced.

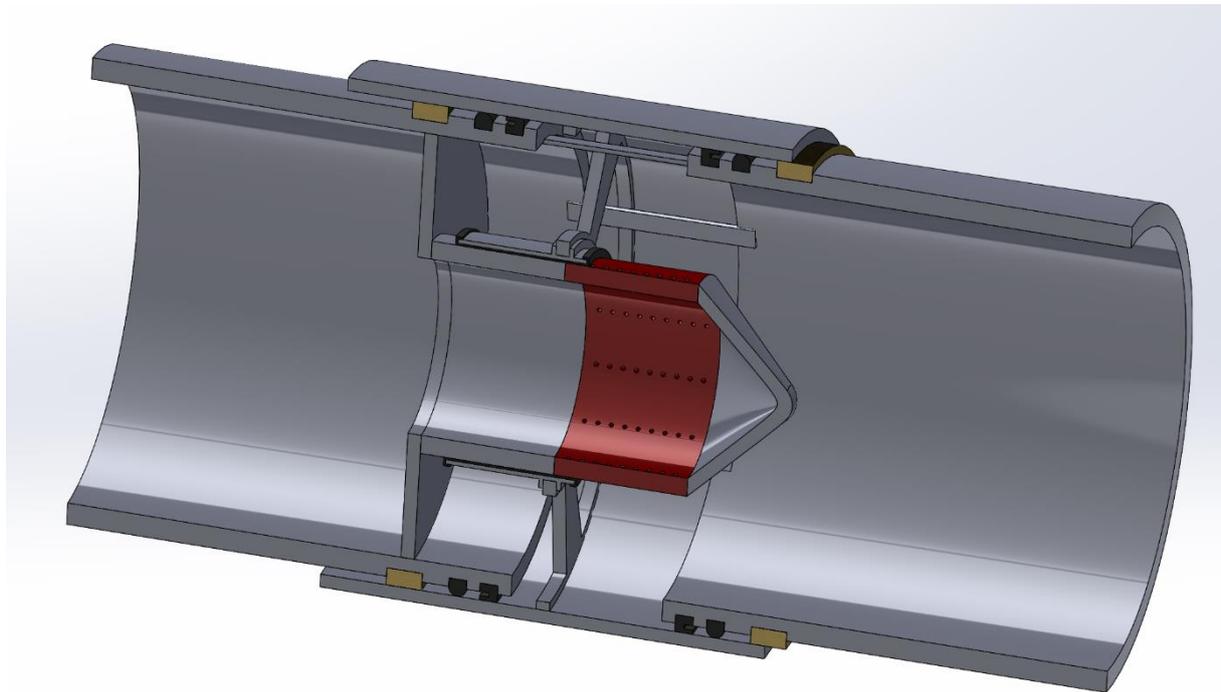


Figure 57: Stiffeners have been added to connect the front- and back-pipe. Increment three

4.5 Forth increment

To increase the stiffness of the system further, the front and back pipe are now made into one pipe. This will not only make the system safer and more reliable, but will also make it easier to install at the facility.

To allow for controlling of the system, holes are cut out along the sides. Through these holes the movable parts will enter the pipe. The movable wall is now replaced by arms reaching from the movable pipe to the foot. By utilizing holes like these, the sealing can now be moved to trace around the holes rather than the whole pipe. This will significantly reduce the amount of sealing needed. Seeing as only the holes must be covered to get a completely tight system, the movable pipe can now be trimmed. This will save material and increase accessibility.

By cutting holes like this in a pipe, the structural integrity is significantly weakened.

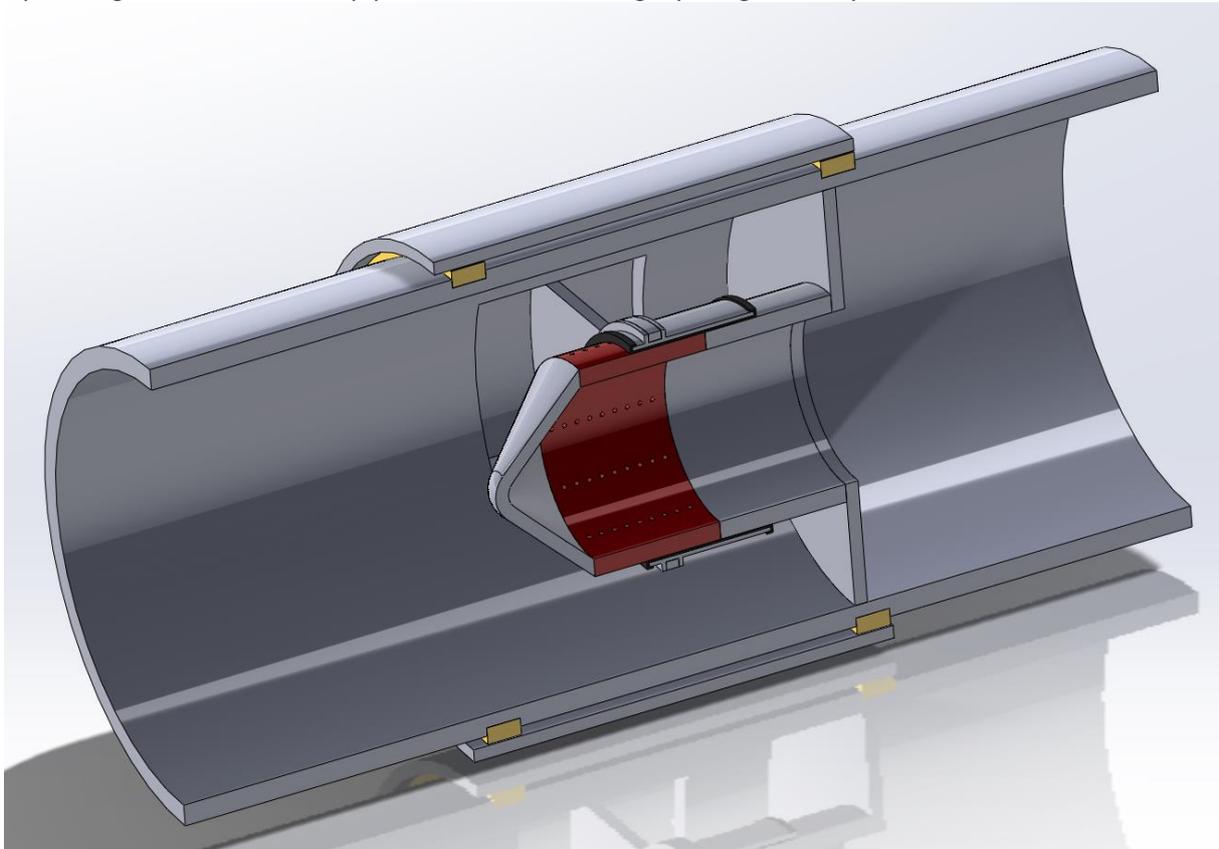


Figure 58: The main pipe is now one piece. the movable pipe has therefore been replaced by arms. Increment four.

4.6 Fifth increment

To better accommodate the requirements set by Multiconsult, the pipe dimensions has been altered. This means that the inner diameter of the main pipe is now 620mm.

It has become prominent to the group that the structural integrity of the system relies heavily on the holes along the side of the main pipe. By keeping the holes as small as possible, the strength of the pipe increases. The arm has therefore been placed horizontally to minimize the height needed. The minimum length of the hole is the length of the perforated pipe, the perforated pipe extension and the arm width combined. Because of this, the arm has been trimmed down to 100mm in width. This will make the total length of the hole 700 mm. Moreover, an update of the calculation related with the RQ-5 and the pipe diameter has been done. And also, it has resulted in increasing the pipe diameter.

In this increment, the holes have been made bigger. This is done to allow for the correct flow rate and flow-characteristic through the system (*explained in the second increment of the Technical document: Flow optimization*). The hole-pattern on the perforated pipe is now three rows of ten holes each.

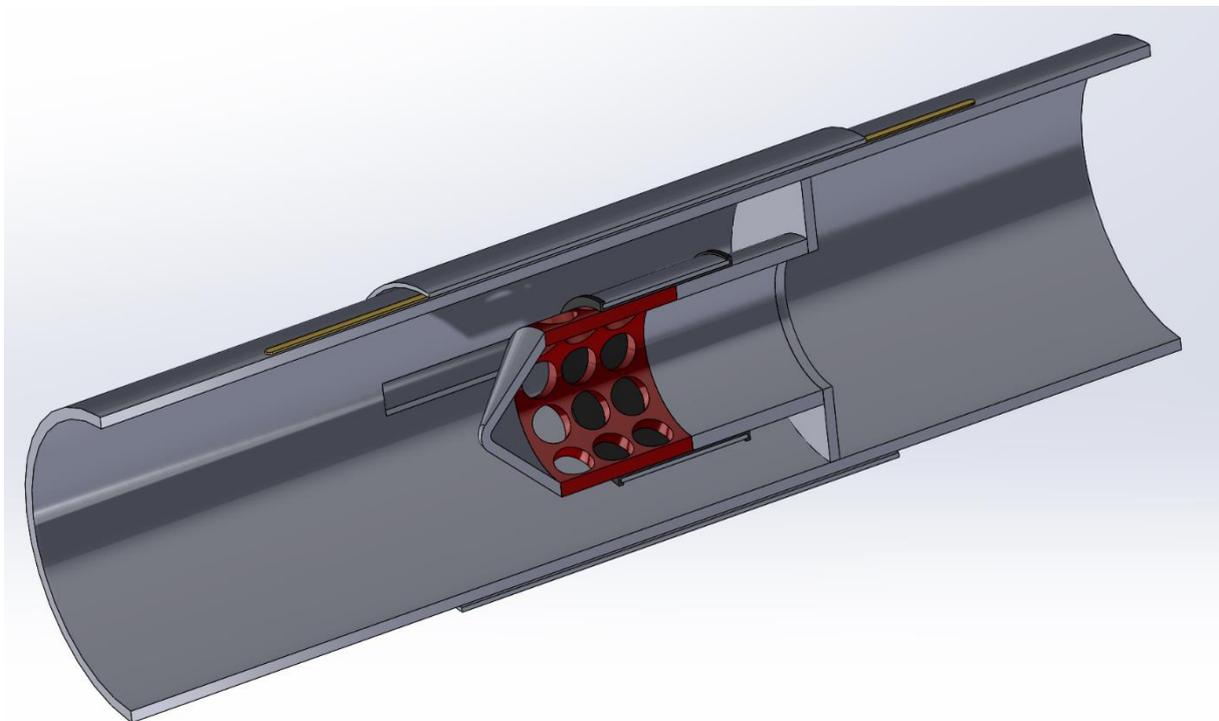


Figure 59: The holes in the sides of the pipe has been altered to better handle the stress. the holes in the perforated pipe has been changed to better accommodate the requirements set by Multiconsult. Increment five.

4.7 Sixth increment

Due to deformation in the pipe, primarily around the holes, the pipe will have to be reinforced. To do this, there are two alternatives: making the entire pipe thicker or add a rim to the holes. For this system, the more beneficial is to simply reinforce the holes. This is done by expanding the holes to allow for a reinforcement block to be installed.

The reinforcement blocks will be blocks with holes cut out into them. The blocks will also have multiple features milled into them, to allow for other sub-assemblies to be attached to them.

By doing this, the reinforcement blocks will take up most of the strain, which will keep the system from deforming. Although this results in a higher production cost, it is still cheaper than the alternatives. This solution will alter the way the system is sealed and how the movable parts operate. Instead of having a movable pipe around the main pipe, the movable parts are now mounted to brackets that fits in grooves on the blocks. This results in a rail-system which keeps the system aligned while still allowing movement in the longitudinal direction.

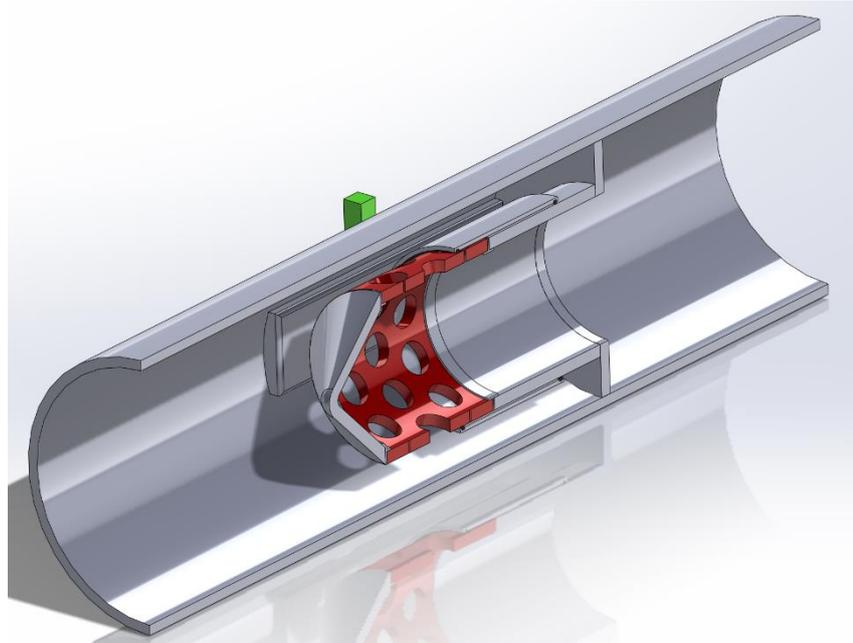


Figure 60: The holes in the sides of the main pipe has been reinforced with reinforcement blocks. The movable pipe has been switched out, and a rail system has been installed. Increment six.

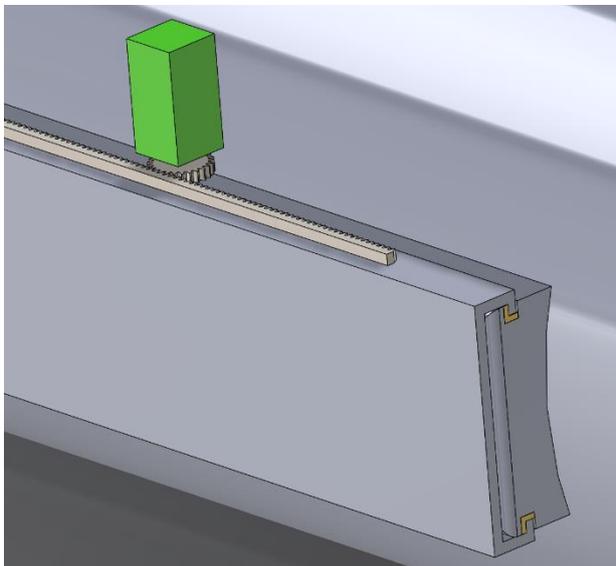


Figure 61: Rail system with movable bracket and representation of the actuator as the green cube.

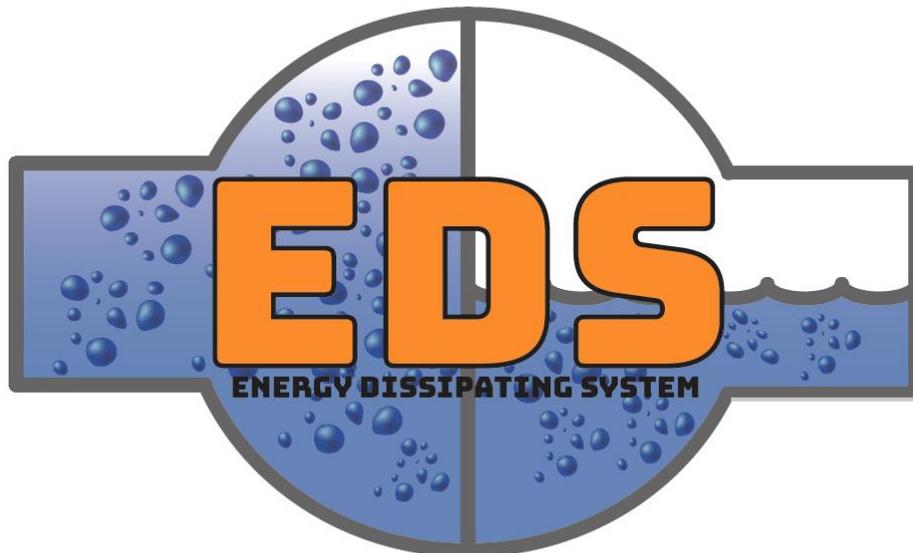


Multiconsult

Design of bypass valve

Technical document: Assembly

22.05.2018



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Abstract

Background: The assembly document gives an explanation of the system. What assemblies and sub-assemblies the valve consist of, an explanation of the parts in these assemblies and how they will be produced.

Method: The different parts of the valve were assessed and discussed in terms of the stresses on the part, the material and cost-efficiency to find the best production method. The parts were designed with a specific production method in-mind. Some of the parts will be bought already assembled, so the discussion in this parts is selecting the right configuration.

Results: The valve body, movable pipe, front cone and perforated pipe extension will be cut, rolled and welded. The reinforcing block is milled from a steel block. The separating wall and arm is cut from a steel plate. The gliding blocks are welded on with a bronze filler wire. The moving bracket and the two sealing are extruded. The perforated pipe will be forged. 2D drawings for all the parts in the valve are included.

Document history

Version	Date	Author	Description
0.00	30.04.18	OO	<ul style="list-style-type: none">• Created the document• Structured the document
0.01	01.05.18	OO	<ul style="list-style-type: none">• Added context to “valve body assembly” and “Inner parts assembly”
0.02	03.05.18	MH	<ul style="list-style-type: none">• Added part descriptions
0.03	06.05.18	OO	<ul style="list-style-type: none">• Described production method for all the parts
0.04	08.05.18	MH	<ul style="list-style-type: none">• Updated pictures and captions
0.05	09.05.18	LH	<ul style="list-style-type: none">• Added references
0.06	19.05.18	LH	<ul style="list-style-type: none">• Added abstract and proofreading
1.00	22.05.18	OO, MH	<ul style="list-style-type: none">• Proofreading• Changed reference setup

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1 Introduction

The system consists of multiple sub-systems which in turn consists of several parts each. How these sub-assemblies will be assembled and how the parts will be produced are two crucial factors when it comes to designing the system. If these factors are not considered when designing the costs can quickly rise or it might even be impossible to produce, realistically speaking.

Although the main system and main parts are in place, there are still some modifications needed. How all the parts will be connected are not yet finalized, and changes might occur. There are multiple ways of connecting parts together, where bolts or welding are the most common ones. The system will mostly utilize these two types of fastenings, but which type will be used where might change at a later stage. This is kept in mind when designing so that the parts will fit, or can easily be changed to fit, no matter which connection method is used.

Another important aspect is how the components and sub-system interact. What type of seals and where they are placed will critically influence how well the system works, if it's tight and the amount of friction between the parts.

The design of each part is a product of the optimal design as well as the way it will be produced. The design will be altered in order to make the production of the part as simple as possible, as long as it does not include too significant changes to the part.

2 List of assemblies

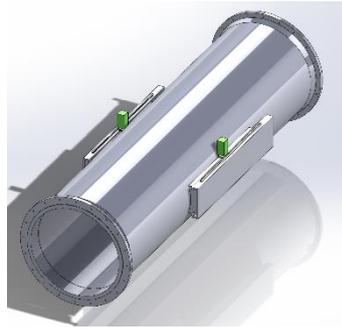


Figure 62: The complete system

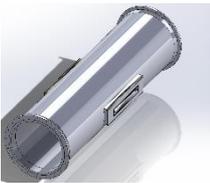


Figure 63: Valve body

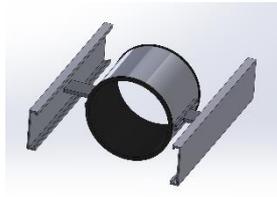


Figure 64: Movable assembly

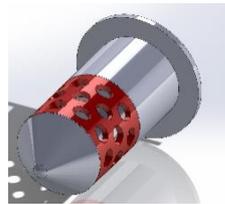


Figure 65: Internal assembly

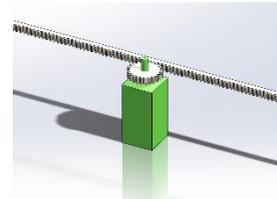


Figure 66: Actuator

Assembly	Parts
Valve body	Main pipe
	Reinforcement block
	Gliding block
	Square sealing
	Flange
Movable assembly	Moving bracket
	Arm
	Movable pipe
	Movable sealing
Internal parts	Front cone
	Bracket
	Perforated pipe
	Perforated pipe extension
	Separating wall
Actuator	

Table 19: Gives an overview of the assemblies and its related parts. The actuator has no associated parts described because it is more an illustrative assembly design. This will be described more in detail in the actuator chapter.

3 Valve body assembly

The valve body assembly will work as a base for the entire system. This assembly will work as a support structure for the other sub-assemblies. This is also the sub-assembly that will be connected to the rest of the facility. For these two reasons, it is essential that the valve body assembly is rigid and that the elastic deformation is kept to a minimum.

The sub-assembly contains five parts; main pipe, reinforcement block, gliding block, square sealing, and the flange. The flange works as the connection mechanism to the rest of the facility, while the other parts mentioned will help in connecting to the other sub-systems.

Underneath is a visual representation of the sub-system.

3.1 Assembly

Number	Part
1	Main pipe
2	Reinforcement block
3	Gliding block
4	Square sealing
5	Flange

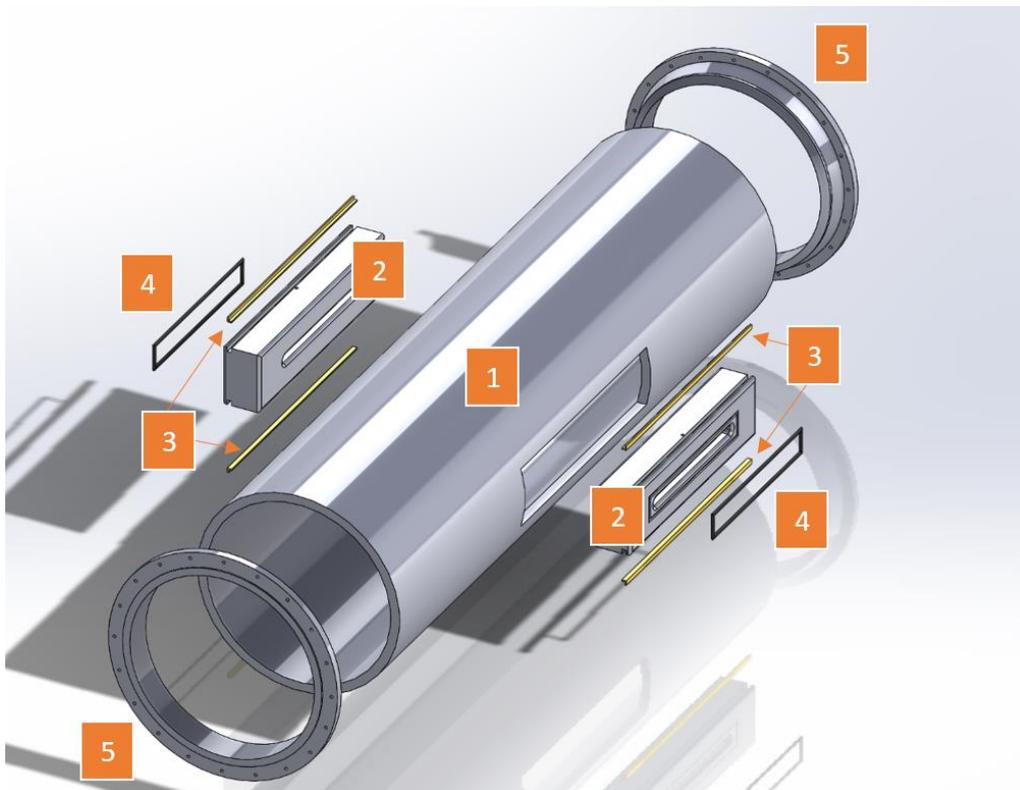
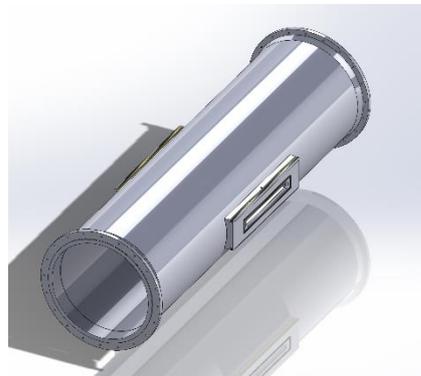


Figure 67: The valve body assembly. The part number in the exploded view correlates to the information in the table. On the right side of the table, the valve body is illustrated in its assembled state.

3.2 Main pipe

The main pipe is the part that will contain the valve trim and the control mechanism. The pipe will be flanged and connected to the pipeline. It is therefore essential that the pipe is rigid, and will not deform under pressure. Deformation of this pipe can cause jams or leaks in the rest of the system

The pipe has two square holes in it. These will allow for operating the system from the outside. These holes will significantly weaken the structural integrity of the pipe, meaning they will have to be reinforced. This is done by introducing “reinforcement blocks,” which is further documented under Chapter 3.3, “Reinforcement blocks.”

The pipe measures 620mm in inner diameter with a 25mm wall thickness, making the outer diameter 670mm. These measurements are a product of the FEM analysis. With these measurements, the maximum stress experienced in the pipe is 144 MPa, which is further documented in the “*Technical document: FEM*”.

The holes are cut out on each side of the pipe, parallel to the ground. Each hole is 800mm wide, 200mm high and goes through the entire wall thickness. Both holes are centered in the pipe.

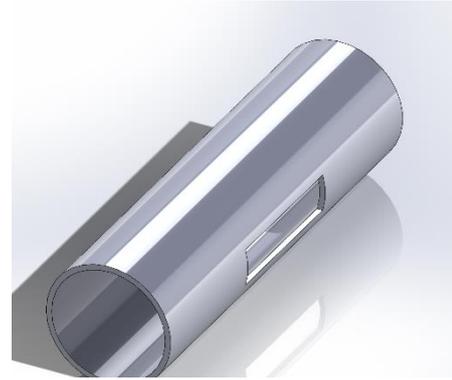


Figure 68: The parametric design of the main pipe.

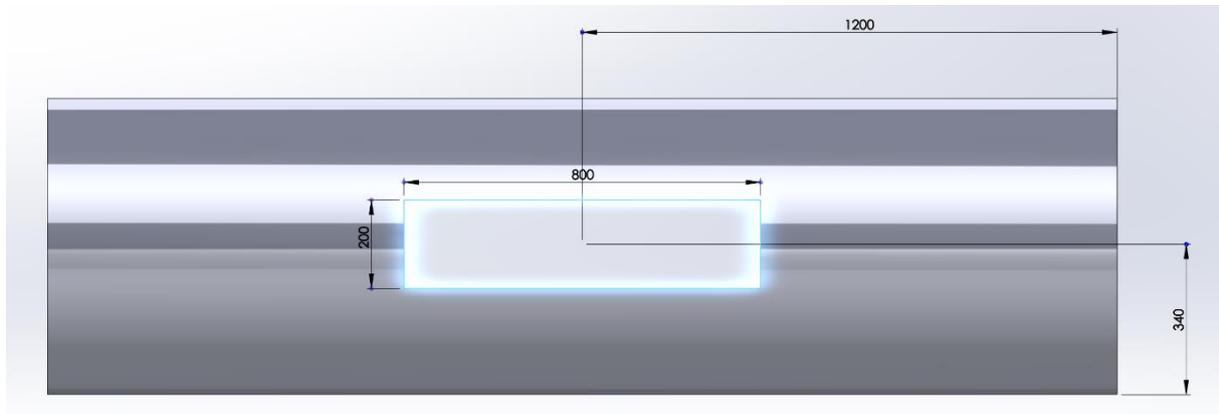


Figure 69: Main pipe side-view. The square hole is centered on both the X- and Y- axis. It measures 200mm high, 800mm wide and through the entire thickness of the main pipe.

3.2.1 Production method

The valve body has a cylindrical, simple shape. The part does not have any complicated geometry which makes it versatile towards different manufacturing methods. The group evaluated casting to be the most appropriate choice for manufacturing method, as it was explained to be reasonably cheap. After conversations with our stakeholder, Multiconsult, the group was informed that casting is a cheap production method, but only in mass production. In our case, mass production will most likely not be the case. Scalability is one of the system requirements, and the requirement will then be related to the selection of manufacturing. Having a production method that easily allows customization and small changes to the design will, therefore, be emphasized. The best production method for the scale of which the bypass valve is produced is plate rolling, where the steel plate is rolled to cylindrical shape. Also, the main pipe has a fixed diameter which makes it suitable for rolling. The argument can be supported by looking at similar applications like pressure vessels. Pressure vessels are specifically designed to withstand high pressure, and these constructions are made by rolling metal plates.

The main pipe will also have to be cut to make access to the movable assembly. A proposed production order may be:

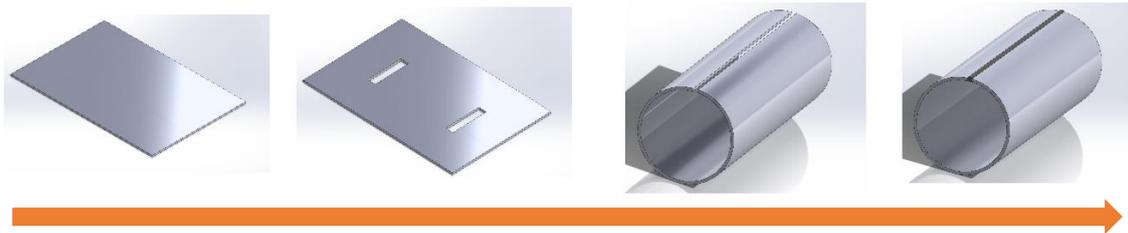


Figure 70: The valve body manufacturing process. A plate will be cut out then be rolled into a pipe and welded together.

Cutting

The two holes for the control mechanism and the reinforcing blocks have to be cut before the plate is rolled. There are several ways to cut steel plates where some are suited for thinner plates, some for thicker plates, some are cheaper with lower quality and some more expensive. The four most common methods are; Oxy-fuel, plasma, laser and waterjet cutting. These methods will briefly be explained and discussed.

Waterjet cutting uses water to cut the metal. The water is forced through a nozzle at very high pressure (ESAB, 2018). This method will leave a smooth and extremely accurate cut, and with no heat distortion. The disadvantage is that water jetting is expensive. In cases where the quality is more important than the cost, water jet will be a valid choice, but for the bypass valve this is not the case.

Laser cutting is at its core a “burning process” (ESAB, 2018). Lasers are amplified through lenses to increase the energy. It delivers a reliable operation and smooth edges. Laser cutting is suitable for plate thickness up to 3.175cm (1.25 inches). The main pipe much thicker than this, and is not suitable for the bypass valve.

Plasma cutting delivers a high-speed production but has lower quality on the cutting edges (ESAB, 2018). Similarly to laser, plasma cutting is best suitable for plates ranging from 0.635cm (¼ inches) to 3.81cm (1.5 inches) and is also not usable for the valve.

Oxy-fuel cutting is described as a “flame” cutting method. The process is a simple and cost-efficient process, where the equipment is relatively inexpensive (ESAB, 2018). The general cutting range is between 2.54cm (1 inch) and 30.48cm (12 inches). In light of these facts the group considers the oxy-fuel cutting to be the appropriate cutting method.

A concern that needs to be watched is the heat-affected zone (HAZ) in the material (Inspectioneering, 2018). The HAZ is the zone where the material has not been melted but has been heated. This can cause changes in the microstructure and material properties may be altered.

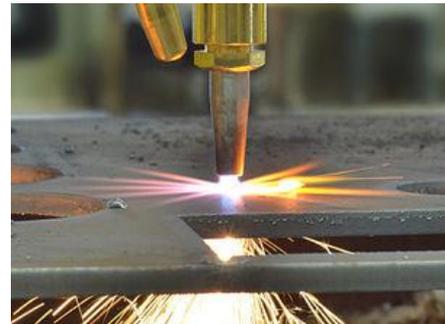


Figure 71: Oxy-fuel cutter piercing through a steel plate. The group sees the oxy-fuel cutting method to be an applicable choice. (Fab-Cut systems, 2018)

Plate rolling

At this point, the plate is cut and the next objective is to form the steel plate into a cylindrical shape. The machining process used for this objective is a method called plate rolling or roll bending (Heston, 2012). The task is carried out using three rollers, two at the bottom and one at the top. The pitch variable work by having the top roll moving in a vertical direction and one or both of the bottom rolls in a horizontal movement. As a result, you can have any desired conical shape.

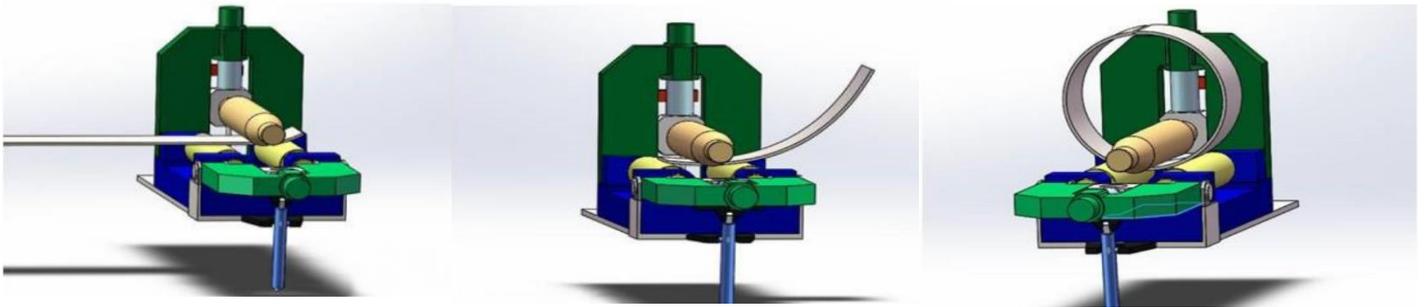


Figure 72: Plate rolling process where the plate through several passes get shaped into a pipe. (Machine Mfg, 2018)

Welding

The last process will be to join the ends of the rolled plate. Seeing as the connection will be fixed, welding will then be the most common choice. A typical welding technic used for connecting the pipe is a technic called butt welding (Kumar, 2018, s. 5). In Figure 73 you can see the red part which is the seam. The welding seam will in most cases have poorer mechanical property then the base material because of the recrystallization caused by the heating. In light of this fact, the welding seam should be adequately tested to ensure satisfactory mechanical strengths. Typical test methods used to ensure no defect in the weld is non-destructive testing, abbreviated to NDT. NDT is test methods that will not damage the weld or work piece. Some conventional NDT test methods used today is visual testing (VT), radiographic testing (RT) and magnetic particle testing (MT).

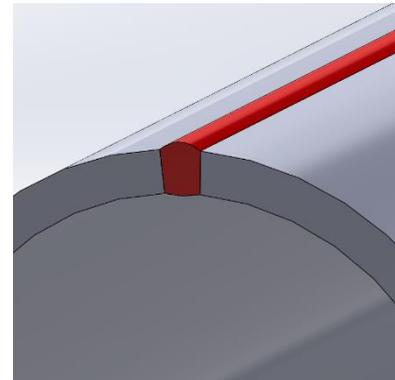


Figure 73: Butt welding seam highlighted in red. The gray part is the main pipe.

3.3 Reinforcement block

The primary goal of the reinforcement blocks is to reinforce the holes so that the main pipe does not deform. These blocks will be welded into place in the main pipe, making them a permanent fixture. Each block has a hole where the arms for the control mechanism will go through. Since the valve requires movement to be opened and closed, it is important that the hole is long enough to open and close the valve fully. A longer hole also means a more substantial weakness in the structural integrity of the block, ergo it is beneficial to keep this hole as short as possible.

The block has three milled slots in it; two working as rail-guides and one to make room for the square sealing.

The slots on the bottom and top stretches the entire length of the block. The slots are 15 mm deep and 15mm wide. Inside each slot, a guiding rail will be installed. These measurements might vary, as they must fit the movable bracket.

The slot on the front face will hold the square sealing in place. This groove has to be tight enough to hold the sealing in place tightly, but also big enough to allow for some flexibility as the sealing is made of rubber and will flex to some degree. The slot traces around the hole in the block, measuring 550mm in inner length with a height of 70mm. The slot is 5mm deep and 10mm wide. These measurements are not critical, as long as the slot is deep enough to hold the sealing in place.

On the top of the block there is a hole. This hole is put in place to secure the actuator to the block. The hole has a diameter of 10mm and is 10mm deep. It is centered on the length and is placed 37mm from the face of the block. These measurements are subject to change as the actuator setup is not fully developed.

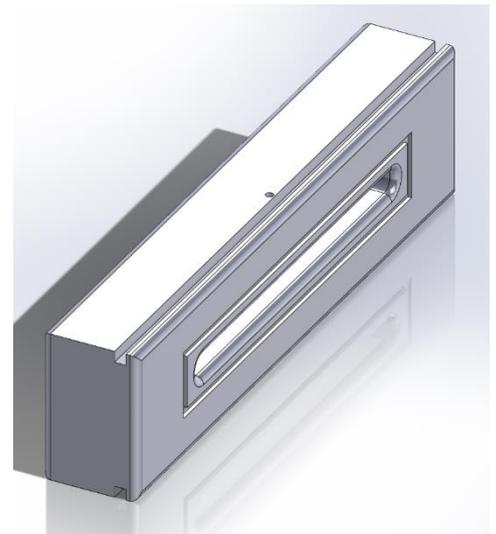


Figure 74: Overview of the reinforcement block. The right face (visible) will face outward of the system, while the left side (hidden) will face towards the center of the system.

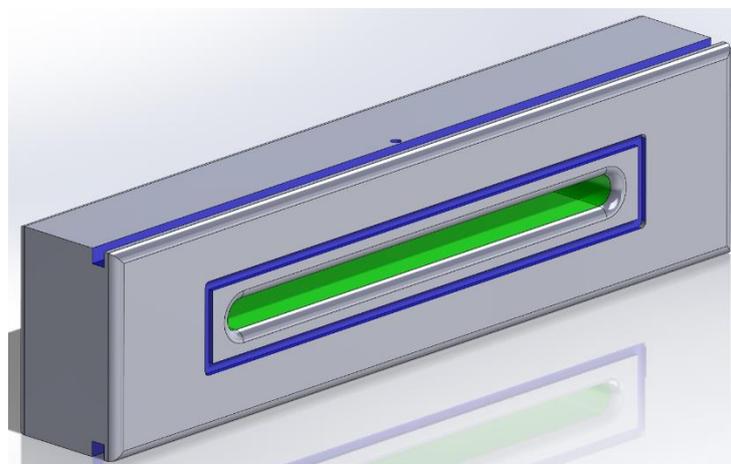


Figure 75: Reinforcement block with 3 milled features highlighted in blue and the main hole highlighted in green

3.3.1 Production method

The reinforcement block has square-shaped form, so a simple steel block will be suitable. The guiding blocks are intended to be installed in “carved shapes” in the reinforcement block. To achieve such a task, the machining process milling is often used. The milling process is executed by using rotary cutters which will be feed into the workpiece (Mousavi, 2016). Different milling methods are usually divided into the two groups based on the rotation relative to the workpiece; vertical or horizontal. For this particular case the vertically milling process, face milling, will be used. Face milling is one of the most common milling methods and a wide range of different tool can be used (Sandvik, 2018)..

Face milling will in some cases leave a rough surface. (Mousavi, 2016). Seeing as this surface will not be in contact with the movable assembly and just be an application for fixing the gliding blocks this will not be a concern.

The part will be welded into place in the holes cut out from the main pipe. The picture below illustrates where the welding joint will be.

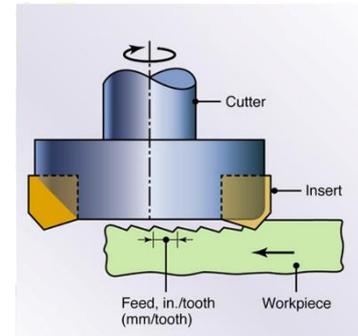


Figure 76: Illustration of a face milling operation where the workpiece is presented as the green part. The milling process leaves a rough surface. (Mousavi, 2016, s. 13)

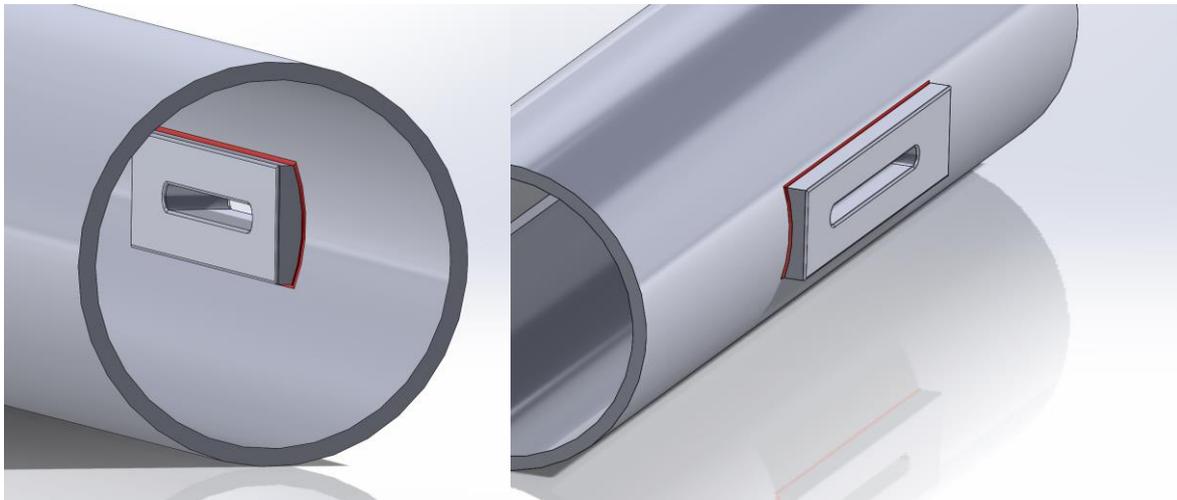


Figure 77: Reinforcement block welded together with the main pipe. The weld joint is highlighted in a red color. The part will be welded both at the inner (left picture) as well as on the outer surface.

3.4 Gliding blocks

The gliding blocks are added to provide less friction for the movable bracket. As this is a metal-to-metal connection that is moving, it is important to keep the level of friction as low as possible. More on this in chapter 3.4.1.

The gliding block will be placed in the slots on the reinforcement blocks, more specifically the slots on the bottom and top of the reinforcement block. The gliding block has an L-shape. It stretches the full length of the reinforcement block, meaning that it is 800mm long. It has outer dimensions of 15mm both ways, with a 5mm thickness. As mentioned above, the gliding blocks will fit into the slots on top and bottom of the reinforcement blocks. If the measurements of the slots change, the measurements of the gliding blocks will change accordingly.

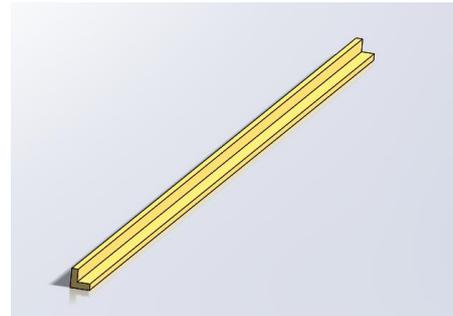


Figure 78: Picture showing the gliding block. As it is symmetrical it can simply be flipped to fit both sides.

3.4.1 Production method

The objective for the gliding blocks is to provide a surface which in the movable assembly can move or glide on. To make the movable assembly move more freely a surface with low friction is preferred. Without some kind of friction reducing measurements, the force required to regulate the valve will be too high. To find a solution the group looked at an existing solution which was operating in the same environment (VAG, 2013, s. 1). After thorough research, the group found a design choice used in the plunger valve. This product is used in the same application where a plunger/piston moves back and forth. This piston moves on something called guiding rails covered in bronze. The guiding blocks are designed on the same principal where it has a bronze covered surface.

The gliding blocks will be manufactured using a metal block in the applicable dimension. The surface in contact with the movable assembly will then be covered in bronze. This will be executed by welding layers of bronze on the surface seen in Figure 79. Using this method will make it easier to apply more bronze if there is occurring some wear (Dynamic fabrication, 2018). The guiding blocks will then be placed in the milled surface on the main pipe and welded together using fillet welding method. Fillet welding method is used for parts standing at an angle or perpendicular to each other.



Figure 79: Welding seam in bronze. The surface in contact with the moving bracket will be covered in the same way where several layers will be applied (WeldingTipsAndTricks, 2018).

3.5 Square sealing

The square sealing works as the barrier between the inside and the outside of the system. The sealing is of the type U-seal. This type of sealing is a unidimensional sealing, meaning that it will primarily seal one way. This is ideal for the system as the pressure will only come from the inside (Apple Rubber, 2016). The sealing will follow the groove on the face of the reinforcement block, meaning that it will have an inner dimension of 550 mm lengthwise and an inner height of 70mm. if the measurements of the groove change, the measurements of the sealing will change accordingly.



Figure 80: Design of the square sealing.

3.5.1 Production method

The sealing will consist of two sealing-rings constructed in EDPM (ethylene propylene diene monomer rubber). The rings are usually created by a combination of extruding and pressing. First the raw elastomer is extruded into the required shape for the ring.

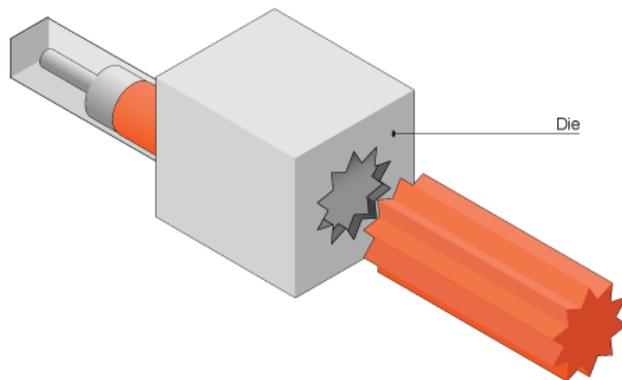


Figure 81: The material is "forced" through a die that has the shape that we want (BBC, 2018)



Figure 82: Elastomer after extrusion. The extrusion process offers a wide range of final shapes and sizes (Axon, 2018)

Extrusion is a process where the material is "forced" through a die which contains a hole which is the same shape as the required product.

After the extrusion process the extruded part is cut to the required perimeter length and then introduced to a press. In the press, due to the high pressure at high temperatures, the circular molded O-ring is created (BER-PA, 2018). After the pressing the O-ring undergoes a de-burring process and oven curing to obtain the required strength.



Figure 83: A mold used for pressing O-rings. The extruded material is cut to length and then placed in one of the circles. After being placed in the mold pressure and temperature is applied and the circular O-ring is formed (ORP Stampi, 2018)

3.6 Flange

To connect the system to the rest of the facility, the system has been equipped with flanges on either end. The flanges are an alternative to welding the system in place. By using flanges, the system is installed more easily and can be removed for service etc.

The flange is a weld neck flange, which is suitable for this kind of use. The flange will be welded on each end of the system.

The inner diameter of the flange is lining up with the inner diameter of the main pipe, which is 620mm. It will be connected to the rest of the facility by 20 m10 bolts. These flanges are standardized.

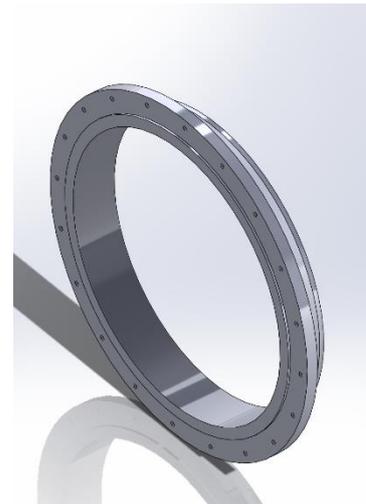


Figure 84: The design of the flange that will be welded to the valve body. This is the part that will be screwed to the rest of the pipeline.

3.6.1 Production method

The flanged connection parts will be connected on each side of the main pipe and will then be the connection between the pipeline and valve. There is wide range of different types of flanges, and it will depend on the system it will be installed into (SunnySteel, 2018). Having the end connection as separate part will make it easier if the customer has some different requirements. For illustrative and explaining reason the group will use the welded neck flange connection.

The end welded neck flange is in most cases manufactured using forging processes. Briefly told the production process will be first to heat a cylindrical metal piece which then get forged, or in other words formed, into the desired shape. Last the holes for the bolt connection will be milled out.

The flanges and main pipe will be merged together by welding. In Figure 86 the connection is illustrated where [1] is the welded end flange, the blue part [2] is the welded joint and [3] is the main pipe.



Figure 85: How the welded end flange will be connected to the pipeline using bolts and nut. (Wermac, 2018)

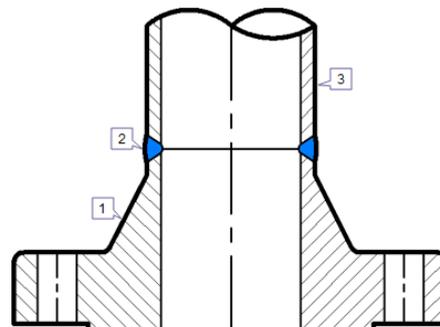


Figure 86: How the welded end flanged connection will be welded together with the main pipe for the valve. The blue section is the joint section. (Wermac, 2018)

4 Movable assembly

The movable assembly is the only moving sub-system in the entire system. It is this sub-system that will connect the outside and the inside of the system. This sub-system will allow for controlling the inside of the system from the outside. The movable assembly will be controlled by the actuator assembly, and guided by the internal assembly as well as the valve body assembly.

The assembly consists of parts on both the inside and outside of the system. The movable assembly is made out of four part; moving bracket, arm, movable pipe, and movable sealing. Underneath is a visual representation of the sub-system.

4.1 Assembly

Number	Part
1	Moving bracket
2	Arm
3	Movable pipe
4	Movable sealing

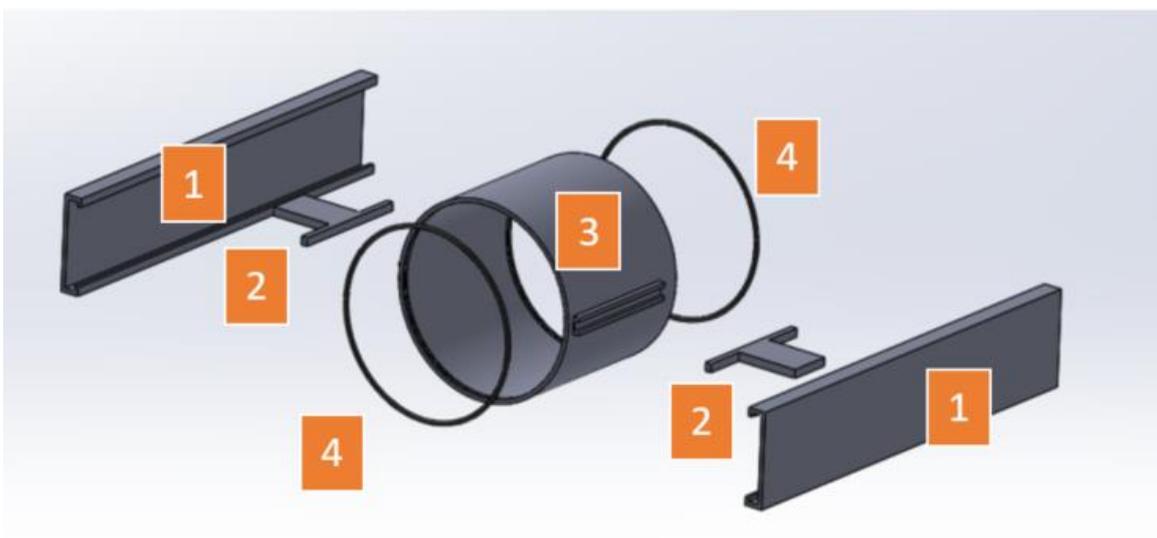
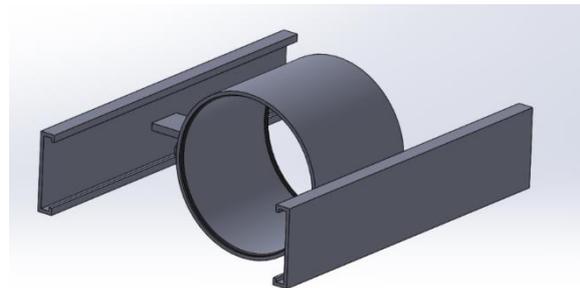


Figure 87: Valve movable assembly. The part number in the exploded view correlates to the information in the table. On the right side of the table the movable assembly is illustrated in its assembled state.

4.2 Movable bracket

The movable bracket is the outside part of the movable sub-system. It is the outmost barrier between the inside and outside of the system. The bracket is mounted on the outside of the reinforcement block. It is done so by being mounted in the slots that is cut out on the top and bottom of the block.

The bracket is made to grab around the reinforcement block and being kept under tension both by the square sealing and by the pressure from the water.

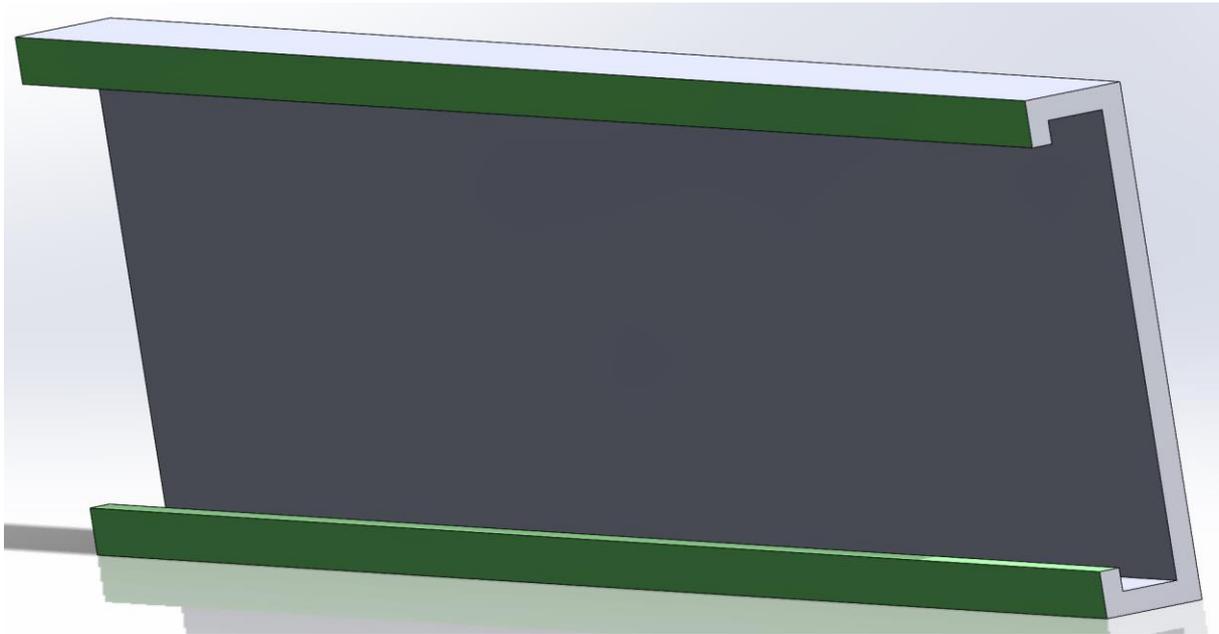


Figure 88: The parts highlighted in green will slide into the slots of the reinforcement bracket.

Its measurements are made to make it fit snugly around the reinforcement block with little room for movement in any direction other than side-to-side. It has a plate thickness of 10mm, which can easily be reinforced if necessary.

4.2.1 Production method

When evaluating the production method of the movable bracket, the group looked at the cross-section of the part. The cross-section is constant throughout the part which makes it suitable for extruding process (CES Edupack, 2011). The manufacturing method is used to make a profile with a given cross-section. The process leaves also a respectable surface finish. The material to be formed will be plastic-deformed by forcing it through a nozzle.

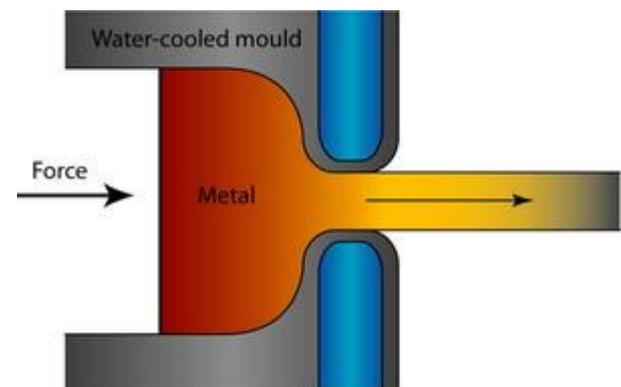


Figure 89: Extruding process where the metal get forces through a nozzle by applying force. (CES Edupack, 2011)

4.3 Arm

The arm works as the bridge between the outer and the inner subsystems. It is connected both to the movable bracket and the movable pipe. The arm has a T-shape to allow for a smaller width of the slot in the main pipe. As the neck of the T-shape will hit the rims of the hole in the reinforcement bracket, a smaller neck will result in smaller holes, which in turn makes the structural integrity stronger.

The arm is 20mm thick to allow for as small slots in the main pipe as possible. The base is 290mm wide while the neck 100mm wide. This means that the neck is thin enough to make the holes in the reinforcement block smaller, but with a wide base to provide stability. The height of the arm is 163.4mm, which is the distance between the movable pipe and the movable bracket. The arm will be welded in place at either end while laying horizontally. The arm has major room for improvements, as it can be trimmed to reduce the weight significantly.

4.3.1 Production method

The thickness is the same throughout the part which makes the use of steel plate possible. By using the same technique as with the main pipe, oxy-fuel, the shape can be cut out. The arm will be welded together with the movable bracket as mentioned in the last chapter, but also with the movable pipe. The connection with the movable pipe is illustrated in Figure 91.

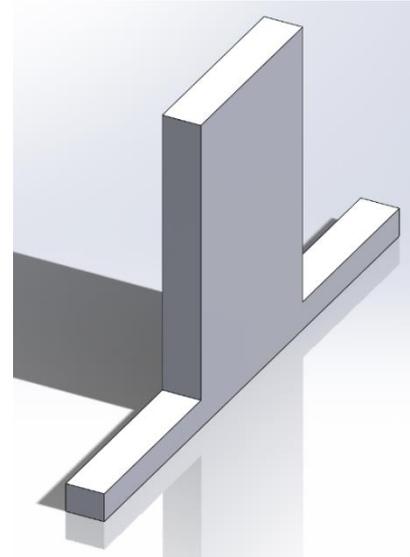


Figure 90: The arm that will transfer the force from the actuator to the movable pipe.

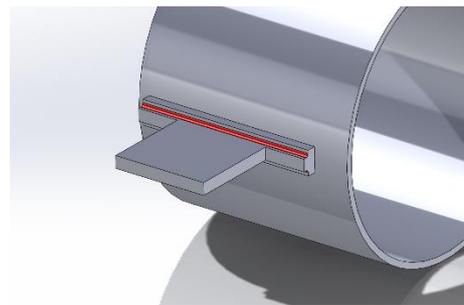


Figure 91: The arm part welded together with the movable pipe. The weld seam is highlighted in red.

4.4 Movable pipe

It is this pipe that is the main restrictor of the water. This will slide on the outside of the perforated pipe and decide how many of the holes on the perforated pipe that will be covered or not, I.E. adjust the flow rate.

The movable pipe is connected to the arm. It is done so by being welded to the arm which lies in grooves placed on the outside of the pipe which the arm fits snugly in-between shown in Figure 91. The pipe measures 430mm in inner diameter. This is slightly larger than the outer diameter of the perforated pipe. It is made this way to make room for the two sealings located on the inside of the movable pipe.

Seeing as a metal-to-metal connection will not be watertight, sealings had to be introduced. These sealings are placed on the back and front of the inside of the pipe. The sealings fit into grooves cut out in the inside of the movable pipe. Although this pipe must withstand a lot of pressure, it is reinforced by the perforated pipe from the inside. This means that the wall thickness doesn't have to be more than 10mm, which will be enough to keep it rigid during movement. The length of the pipe is 365mm, the same length as the perforated pipe.

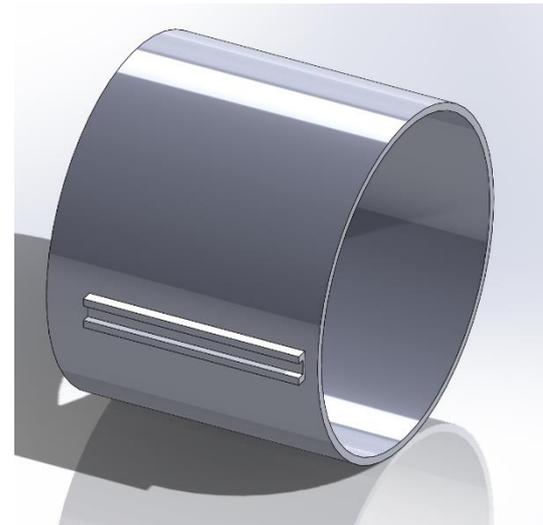


Figure 92: The movable pipe that is responsible for the flow control by covering the holes in the perforated pipe.

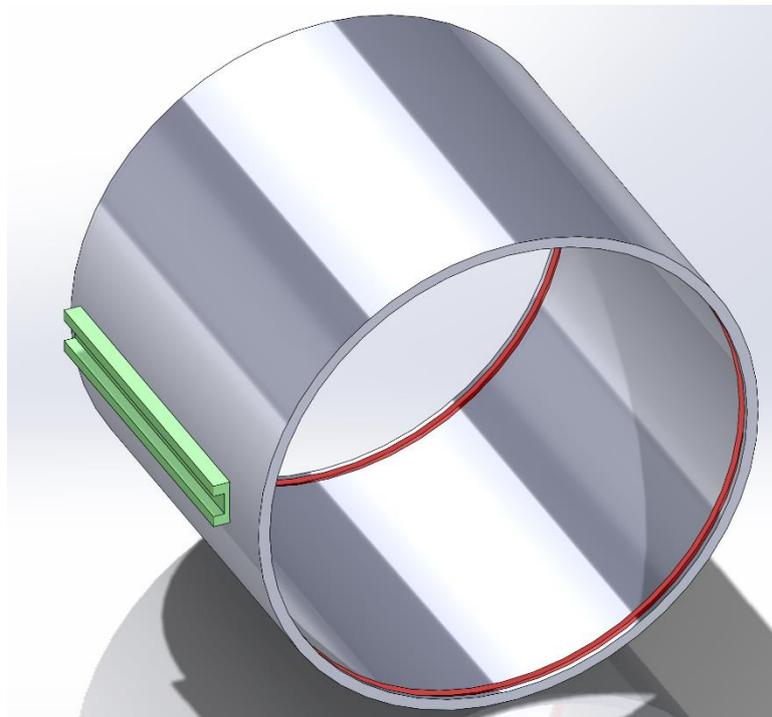


Figure 93: The green part is where the arm will be connected, while the red slots is where the sealing will be placed.

4.4.1 Production method

The production method of the movable pipe will follow more or less the same processes like the movable pipe. The part is somewhat smaller, but the geometry allow for the same production method. The pipe itself will be manufactured from a steel plate. Before it gets rolled and welded together the slots for the sealing has to be milled out. The same milling method used for the reinforcement block, face milling, will be an applicable choice. Last the connection rails for the arm will be welded into place. The whole process is illustrated in the figure below.

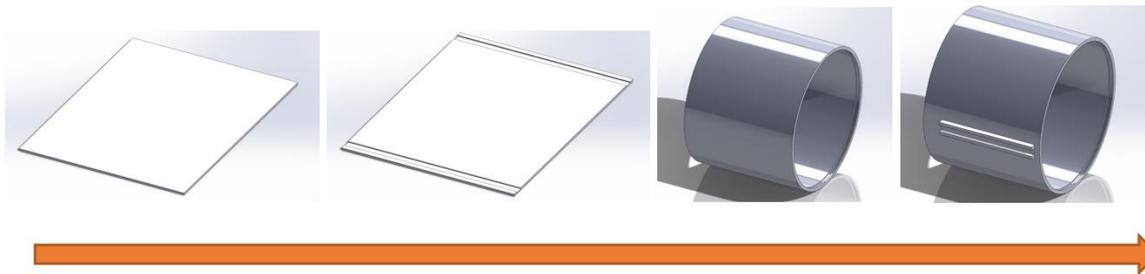


Figure 94: Production method for the movable pipe. From-left-to-right: the first picture present a steel plate which will be milled and the result is illustrated in the second figure. In order to get a cylindrical shape the pipe will be rolled and the result will be as illustrated on the third figure. Figure four show the end result when the rail connection to the arm is welded into place.

4.5 Movable sealing

This is the sealing that fits on the inside of the movable pipe. It is a standard O-ring which will fit in the grooves on the inside of the movable pipe.

As the O-ring will fit on the inside of the movable pipe, the diameter of the O-ring is 430mm. the cross-section of the O-ring is 10mm in diameter. Seeing as the grooves are 5mm deep, the O-rings will rise 5mm from the surface uncompressed.

This is a part that is prefabricated which means that it will be bought from an external retailer.

4.5.1 Production method

The production method for this sealing will be the same as the square sealings described in Chapter 3.5.1.

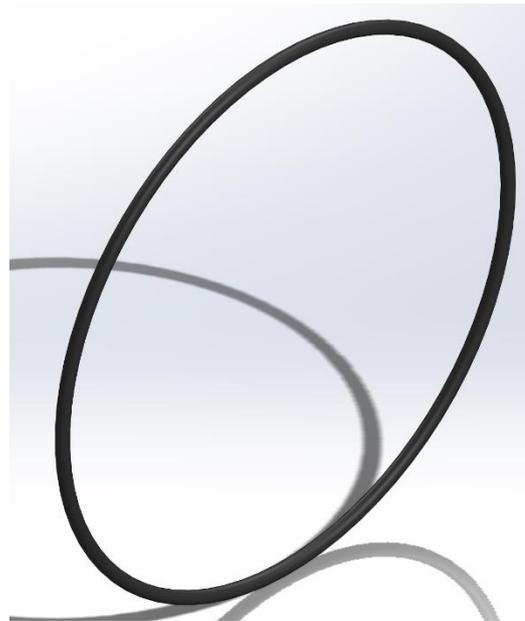


Figure 95: Presenting a parametric design of the movable sealing

5 Internal assembly

The internal assembly, also referenced as the “valve trim” is the parts that will dissipate the energy in the water. The assembly consists of 5 parts: front cone, bracket, perforated pipe, perforated pipe extension, and separating wall. The separating wall will secure the valve trim in place inside the valve body by welding it to the walls.

5.1 Assembly

Number	Part
1	Front cone
2	Bracket
3	Perforated pipe
4	Perforated pipe extension
5	Separating wall

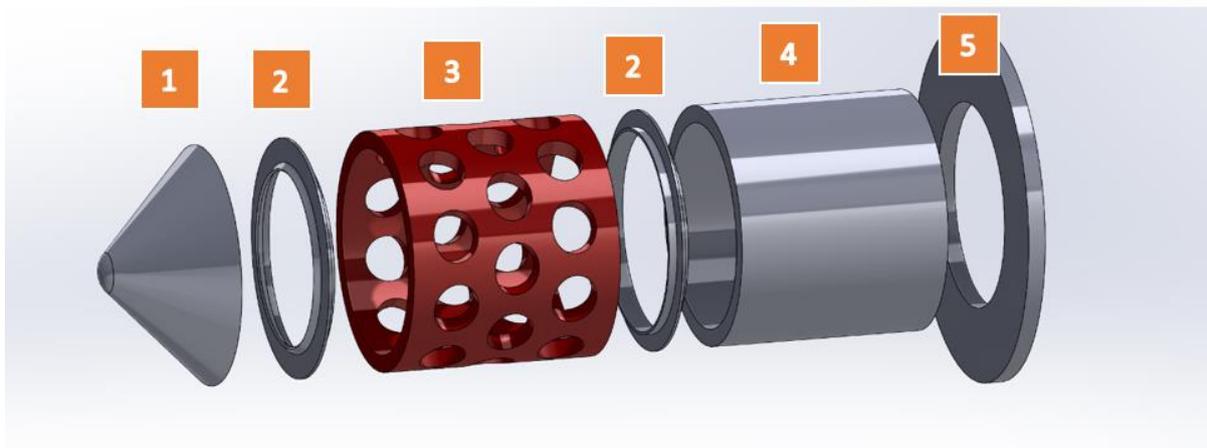
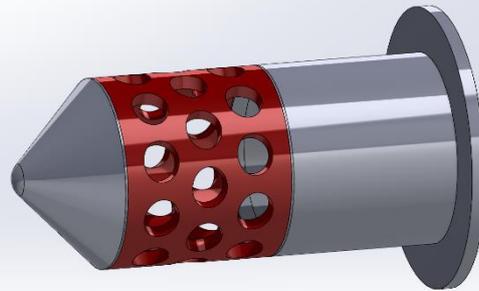


Figure 96: Presents the internal assembly. The part number in the exploded view correlates to the information in the table. On the right side of the table, the internal assembly is illustrated in its assembled state.

5.2 Separating wall

In the internal assembly, the separating wall is the connection to the main pipe. This wall will separate the front and the back of the system, which is the pressurized and the non-pressurized sides. The wall will be welded to the main pipe. On the inner part of the wall, the perforated pipe extension will be connected. This part will also be welded in place.

As this wall will experience the full pressure of the system as well as holding the weight of the system, it is important that it is strong enough to withstand both. It is made from a 30 mm thick plate with an outer diameter of 620mm and an inner diameter of 360mm. This will make it fit with both the perforated pipe extension and the main pipe.

5.2.1 Production method

The separating wall will be attached to the inner surface of the main pipe and will be orientated perpendicular to the pipe. By evaluating the shape of the part a manufacturing method can be decided. The part has the same thickness which makes it versatile towards different production methods. Seeing that already other parts will be made out of steel plates it is convenient to use it to make the separating wall as well. The part will most likely then be produced with a steel plate with the same thickness. Further, will the shape be cut out using the same cutting method as with the main pipe, oxy-fuel cutting. By using the same production methods on a different part, it may be possible to manufacture them at the same place. This can be beneficial in concerns of cost. The separating wall will then be welded together as illustrated on Figure 98.

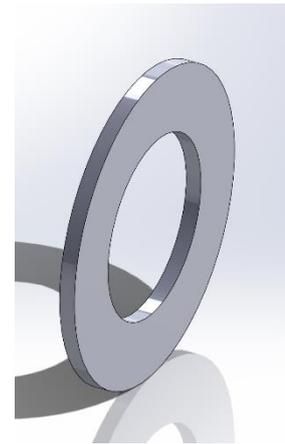


Figure 97: Present the parametric design of the separating wall part

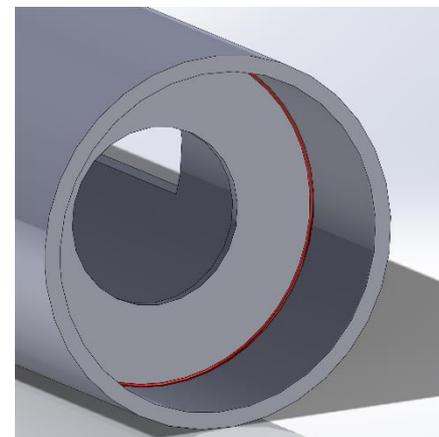


Figure 98: Demonstrating the Separating wall welded together with the main pipe. The weld seam is highlighted in red. It will be a corresponding weld seam on the other side as well.

5.3 Perforated pipe extension

The perforated pipe extension is an extension of the perforated pipe that gives the movable pipe room to move completely off of the perforated pipe. When the movable pipe is not covering the perforated pipe, i.e. when it is fully open, the movable pipe will sit on the perforated pipe extension. The construction of this pipe is rather simple, as it is a straight pipe that is connected to the separating wall at one end, and the perforated pipe at the other. To the separating wall it will be welded, while the connection to the perforated pipe will be done using a bracket to ensure easy maintenance and changeability.

The pipe has an inner diameter of 360mm and an outer diameter of 420mm. The length of the pipe is 365mm. By making it the same size as the perforated pipe, the foot can be moved entirely off the perforated pipe and onto this pipe. Thus making sure that the water is completely unhindered when the system is entirely open.

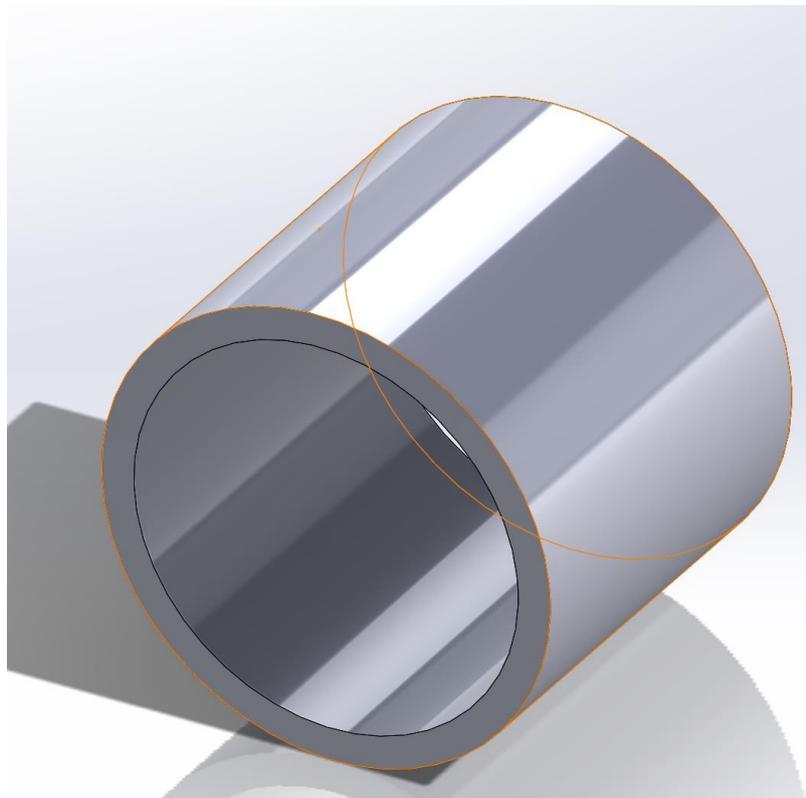


Figure 99: Illustrating the parametric design of the perforated pipe extension.

5.3.1 Production method

The manufacturing of the part will be done in the same order as the main pipe where a steel plate will be rolled and welded together. The only difference is that the perforated pipe extension will not go through a cut operation. The part will be fixed to the separating wall by welding. The weld joint is illustrated in Figure 100.

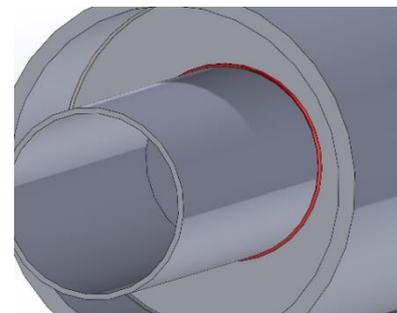


Figure 100: Illustrating the perforated pipe extension welded together with the separating wall. The weld seam is highlighted in red.

5.4 Perforated pipe

The perforated pipe will be the main energy dissipater and has a huge influence on the flow-characteristics, flow restriction and cavitation in the system. The pipe has several holes in it in which the water will flow through. These holes will be covered by the movable pipe to adjust the amount of water allowed through. The pipe is connected by using brackets at either end. This is done so that the pipe is easily changeable and to make service easier. Although the pipe is designed to withstand cavitation etc. it is still most likely that it is on this part that cavitation and erosion will occur.

To allow for optimal flow characteristics, energy dissipation and avoiding cavitation, the pattern of the holes have been designed to include 30 holes spread over three columns. The first and the last column are in-line, while the middle one is offset. This configuration will make the structural integrity the strongest. As with the perforated pipe extension, the inner and outer diameters are 360mm and 420mm. The holes are 80mm in diameter each. This is further documented in the flow optimization (*see Technical document: Flow optimization*).

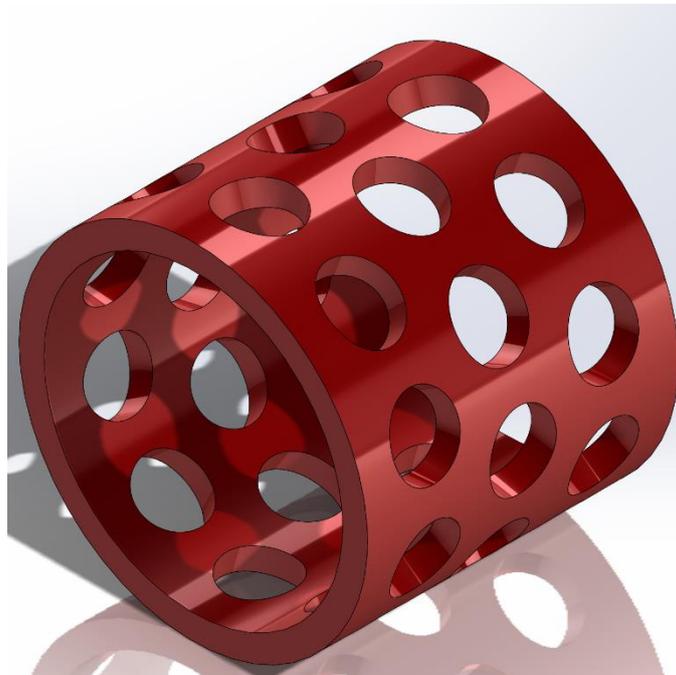


Figure 101: Present the parametric design of the perforated pipe part.

5.4.1 Production method

All of the fluid flowing through the system will go through the part. As a result, the perforated pipe will experience a great amount of erosion as well as corrosion relative to the other parts. In the material selection this was taken into account when selecting. Hence it should be considered in the production method as well.

Forging

Since the perforated pipe requires higher strength and surface hardness, it will be forged. The forging will increase the impact, and shear strength and forged steel are generally stronger compared to casting and steel plates. The reason is that a forged material will go through a deformation process which will result in a grain refinement. A finer grain structure will then again result in a generally stronger material characteristic (ATC Group, 2018). Forging is considered to be the appropriate process. Casting usually cheaper than forging, but in this case, where the material strength is emphasized, the cost has to be compromised. (Borui casting international LTD , 2018).



Figure 102: How a cylindrical shape part will be forged. The group consider the forging to be the applicable process to manufacture the perforated pipe. (Sajay Bonny Forge, 2018)

Cutting

Next operation to be done is to cut out the holes. An appropriate process for this task is drilling. Drilling is a cutting process where the cutting process is performed by piercing a drill bit into the workpiece. From the optimization done in flow simulation a conical shaped hole was presented as the optimal solution, thus a countersink drill bit is required.



Figure 103: Illustrating a countersink bit. (Mac buildingproducts, 2018)

5.5 Brackets

The brackets are designed to hold the perforated pipe in place. By using brackets, the need for welding is eliminated. This will significantly improve the system in terms of serviceability and if parts need changing.

For the system, two types of brackets are used. One straight and one angled. The difference being that on the straight one, both sides of the rim goes horizontally out from the rim. While on the angled, one of the sides goes on a 45-degree angle downward. This is to accommodate the angle of the cone. These brackets are still subject to change as it is not decided how they will be fastened.

5.5.1 Production method

As mentioned the brackets is the part which enables the perforated pipe to be replaced. At this point, the part is too underdeveloped to evaluate the production method in a respectable way. Initially, the group decided to use a type of bracket in collaboration with some type of bolts. This solution proved to be an insufficient choice which will be described more in detailed in the evaluation (*see project evaluation*).

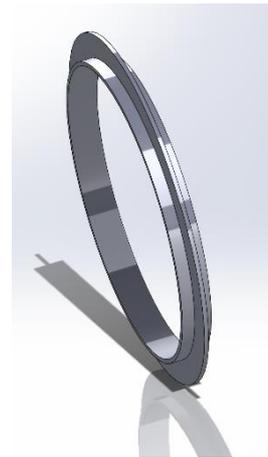


Figure 104: The bracket

5.6 Front cone

The front cones main task is to divide the water before flows through the perforated pipe. The cone has a conical shape to make a more aerodynamic design. The angle of the cone is 45 degrees off of the normal. Which will create the maximum structural integrity. The tip is rounded to eliminate stress points. As this is a tip, it will only be connected to the perforated pipe.

5.6.1 Production method

The conically shaped part has the opportunity to be rolled from plates just like the main pipe and perforated pipe extension with some adjustment. The rolling process will be performed in the same way with one roll on top and two at the bottom. The difference is that the rolls are now conical shaped, so one side has a greater traveling distance than the other. As an outcome, the plate will bend more on one side thus resulting in a conical shape.

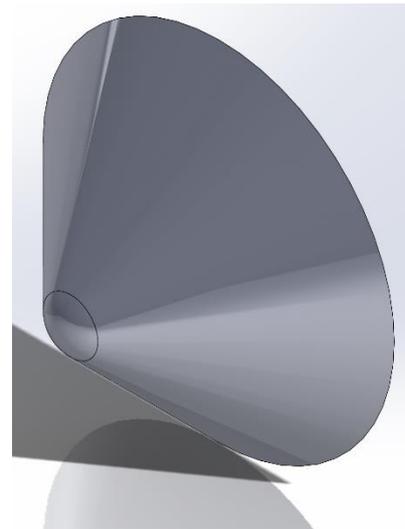


Figure 105: The front cone



Figure 106: A plate roller bending a metal plate into a conical shape. The group sees roll bending to be the applicable production process for the front cone. (HB Machinery Co, 2013)

6 Actuator

The function of the actuator or regulator is to adjust the position of the valve to ensure correct control of the process fluid (Nesbitt, 2011, p. 280). The actuator applies a linear force or a rotary torque to the valve element. According to Brian Nesbitt, the most common and cheapest type of actuator is a pneumatic diaphragm. But there are several other types, such as the electric-hydraulic, vane and piston actuators.

There are generally two ways of driving the actuator, through compressed air or with electricity. Air is a readily available, but it should be dried to some extent before used. This is because the moisture accommodated in the air can cause corrosion in the actuator and may freeze if the temperature is reduced. Water droplets can cause flow problem and in the cylinders, it can cause erratic movement. Compressed air system should therefore be fitted with a separator, traps and drains to remove condensation. Air entering the compressor must be filtered to prevent abrasive elements from entering and causing rapid wear.

Another other “family” is electric powered actuators which can in theory solve all the problems mentioned above. Electric supply is closely regulated and with very low frequency variation, but before choosing an electric actuator the overall electric quality should be quantified. Compressed air is usually produced on site and the quality of supply is under the user’s control. Electricity is from a third-party and extra equipment may be necessary to improve the quality and reliability of the electricity.

Lastly, hydraulic actuators may also be used. These are driven by hydraulic fluid that is pressurized by either electricity on-site, through a power-bank or by using the water pressure in the pipeline (Smith & Zappe, 2004, p. 304).

The types of actuator that are relevant for the bypass valve is either an electric-, electric-hydraulic- or a pneumatic actuator (Nesbitt, 2011, pp. 280,281).

When choosing an actuator for the bypass valve, there are several factors that come into play. The actuator must fulfill several requirements:

- Fairly quick opening action
- Operate safely under 60 bars
- Cost efficient
- Compatible with linear movement

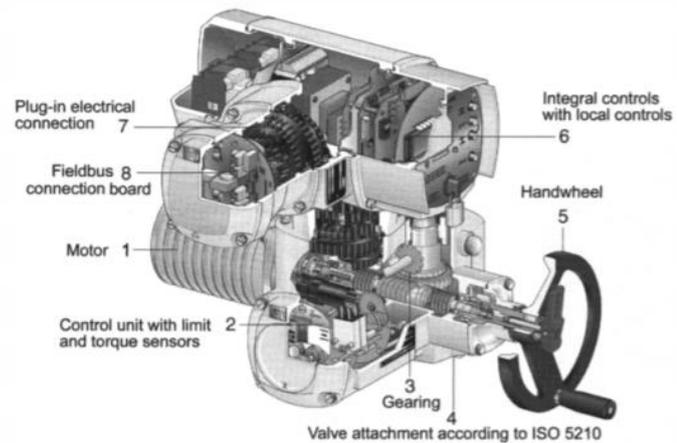


Figure 107: An electro-mechanical actuator (Nesbitt, 2011, p. 292)

- Must be able to control the flow accurately, i.e. precise and controllable movement can hold at a predefined position for more extended periods of time
- Autonomous

The autonomous requirement will most likely be solved with a sensor which monitors the turbine operation and if the turbine stops activate the actuator (Smith & Zappe, 2004, s. 301). The flow through the valve is then adjusted according to predefined data and closed when the turbine failure has been fixed. The pneumatic actuators are eliminated because of their inability to accurately maintained a fixed position because of the air that powers the actuator is a compressible medium.

The other type of actuator is an electric actuator. The advantages of this type are:

- Electric motors run at high speeds that can be geared down to the required torque and opening speed
- Position stability can be maintained
- Compact in design

But there are still disadvantages to the electric actuator such as:

- May be expensive
- Complex in design and requires higher level of maintenance
- Power outages may occur and electrical power is not easily stored
- Must be protected from moisture

Another possibility is using a hydraulic system, either powered by electricity or by the water pressure from the power plant itself. Some of the advantages of this kind of system are:

- May be configured to work at a power-less station
- Hydraulic pressure can be stored in the event of a power outage
- The hydraulic fluid is considered to be incompressible and this results in stability during operation
- Size efficient

Some of the disadvantages of a hydraulic actuator is:

- The cost of providing a hydraulic tubing system is high
- No kinetic energy for hammerblow unseating valves

The actuator that we choose is either an electric actuator where power is available or a hydraulic actuator where the hydraulic energy is either stored or powered by the water pressure in the power plant (Smith & Zappe, 2004, pp. 303-304).

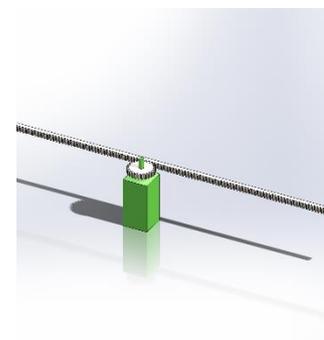
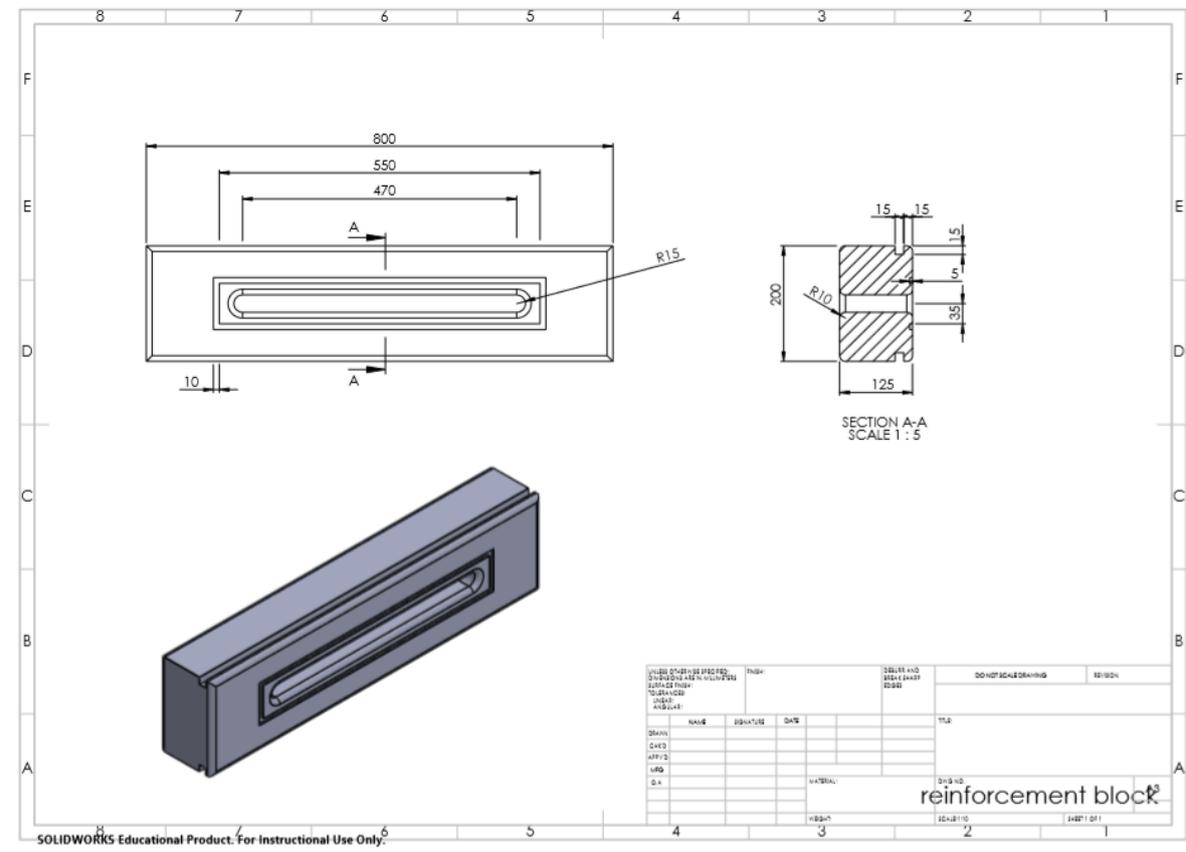
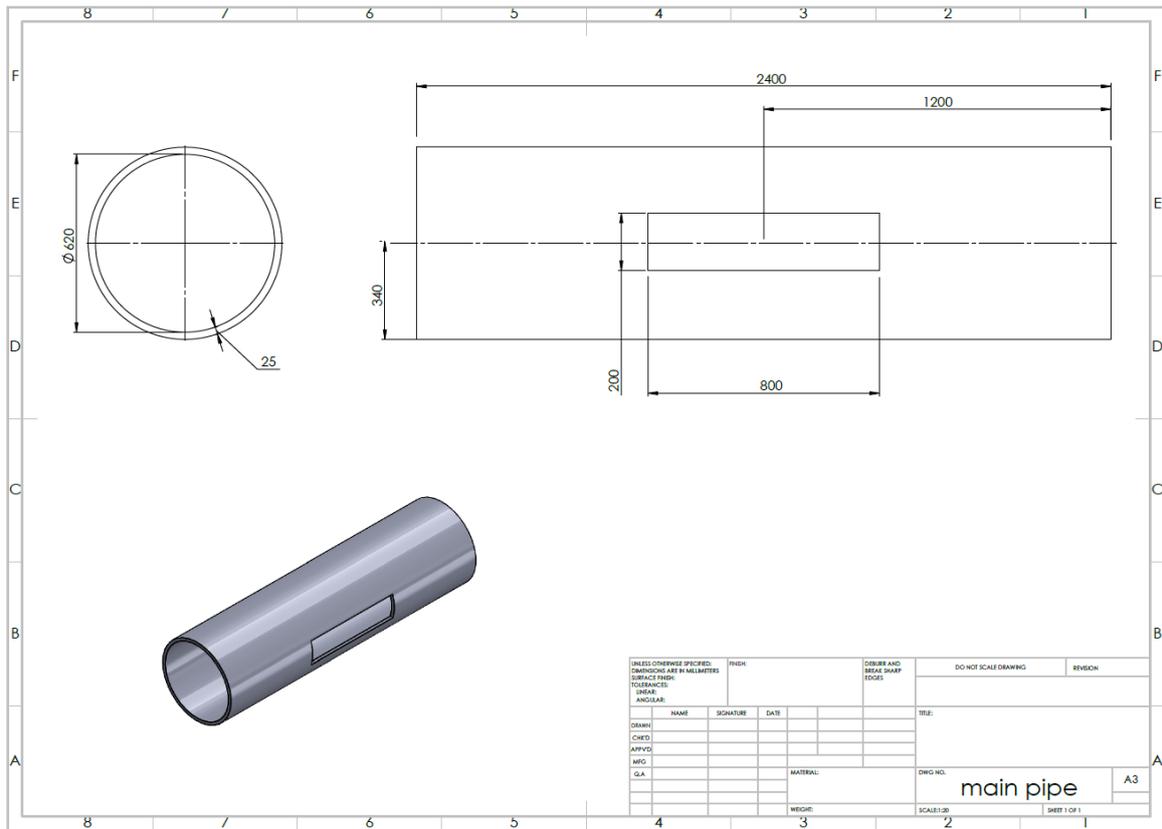
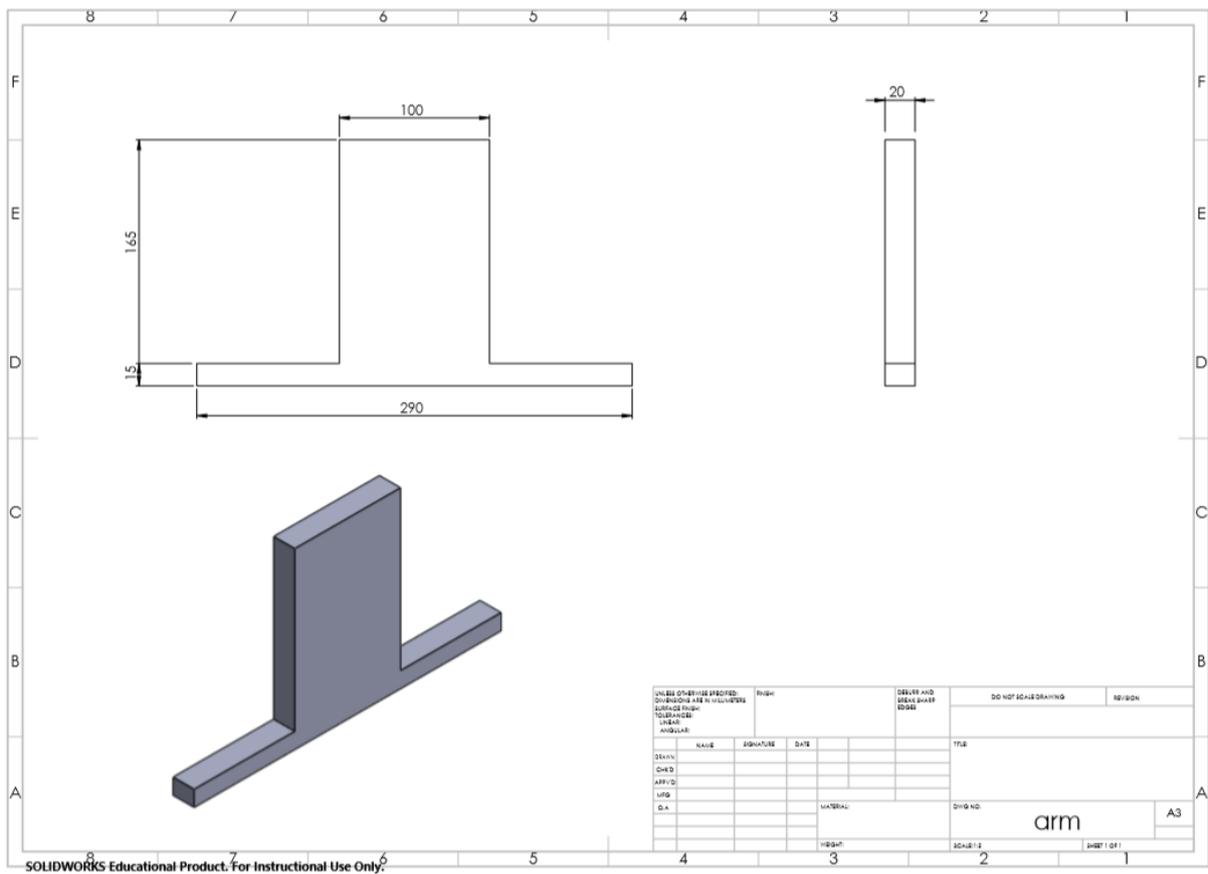
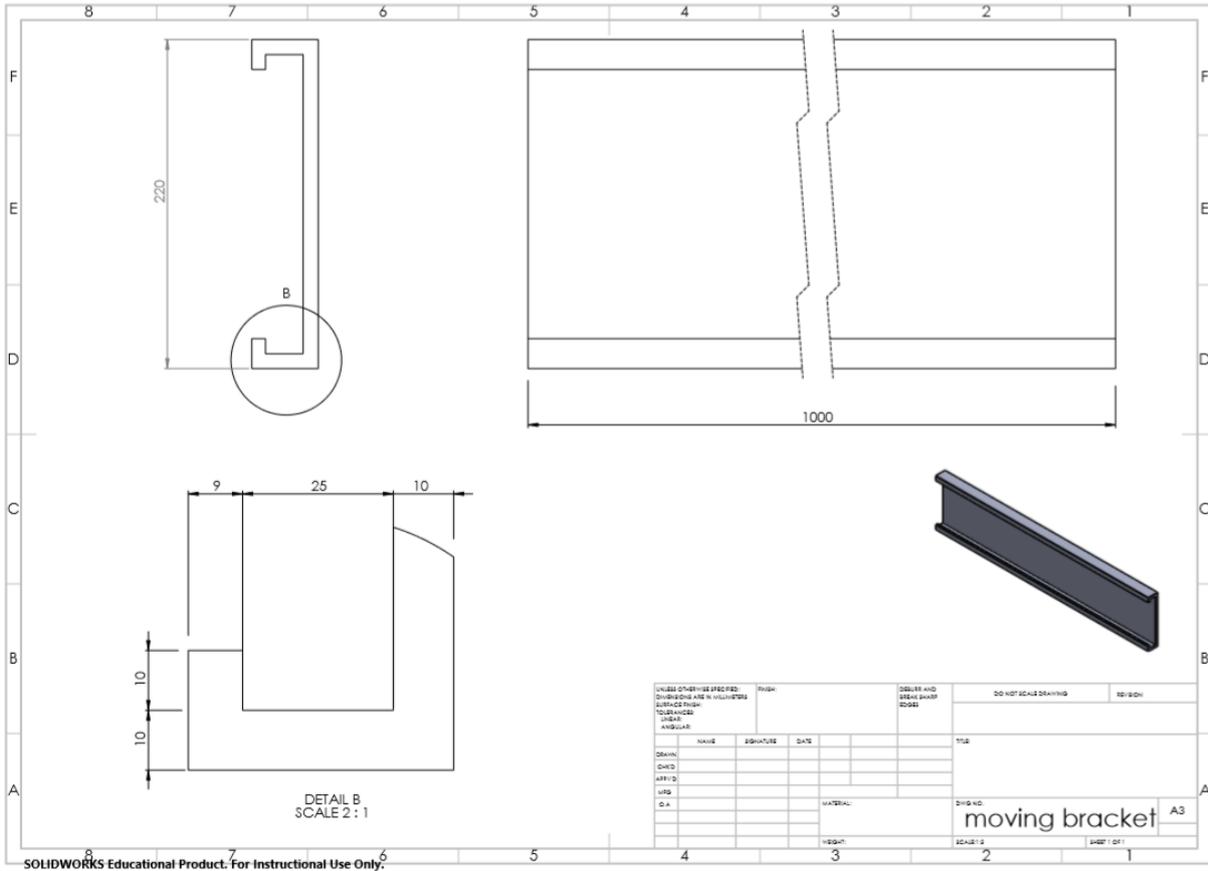


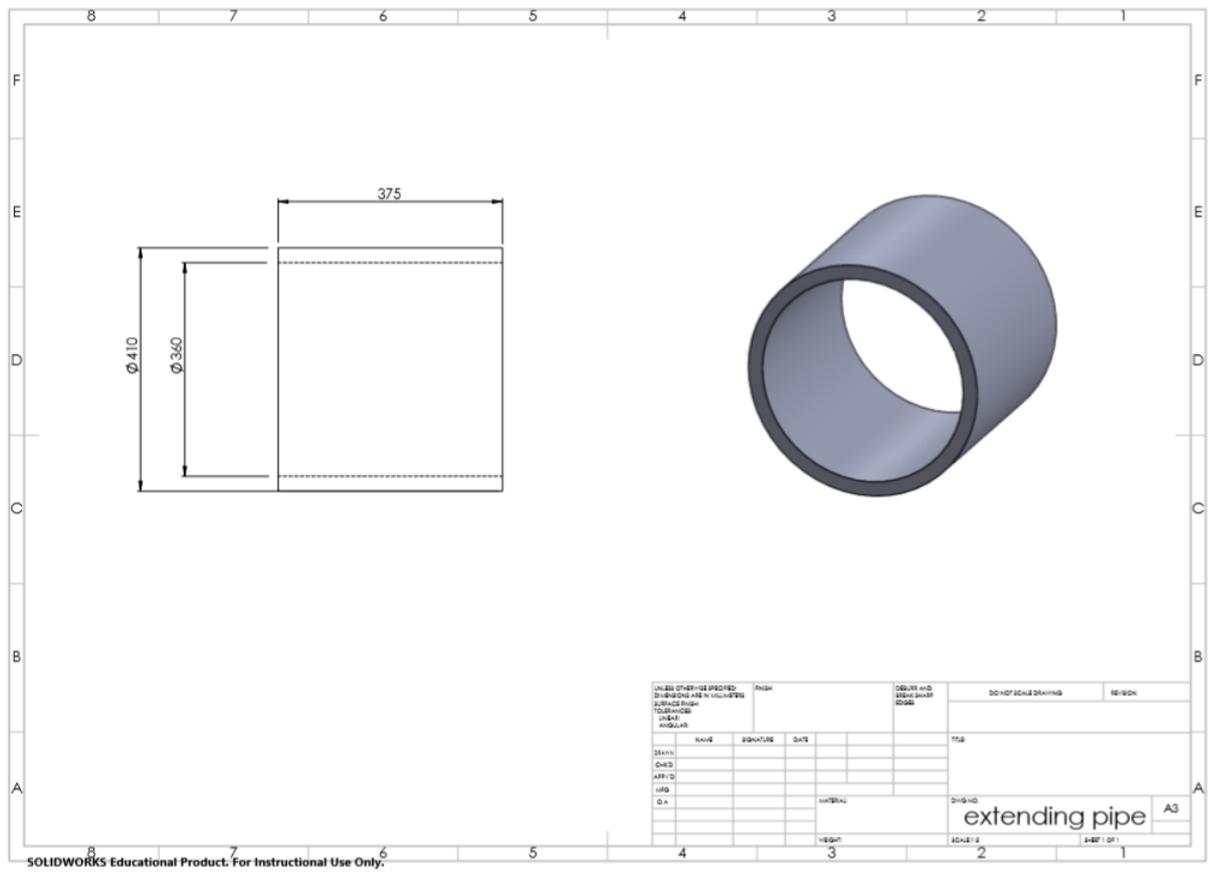
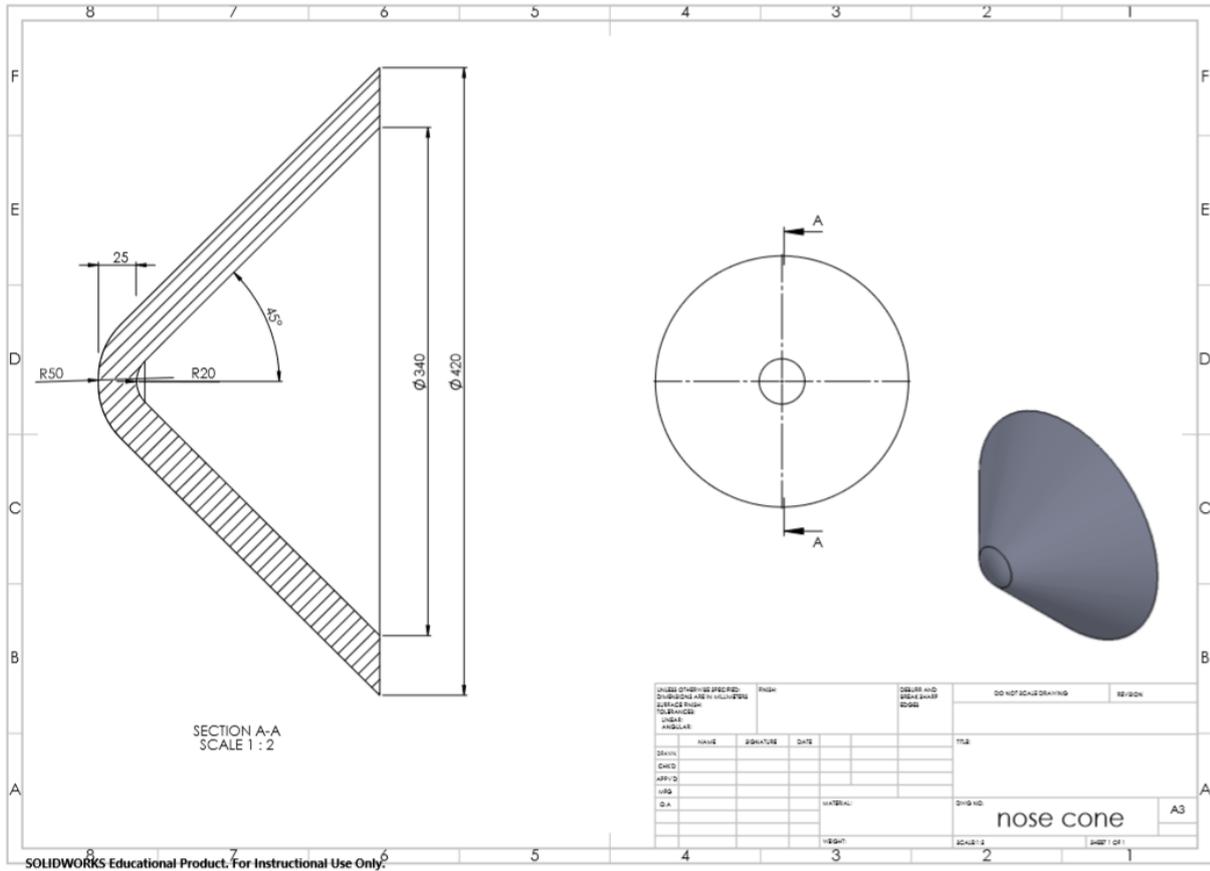
Figure 108: Representation of the actuator in our model. The actuator will be bought and thus it is only a simplification

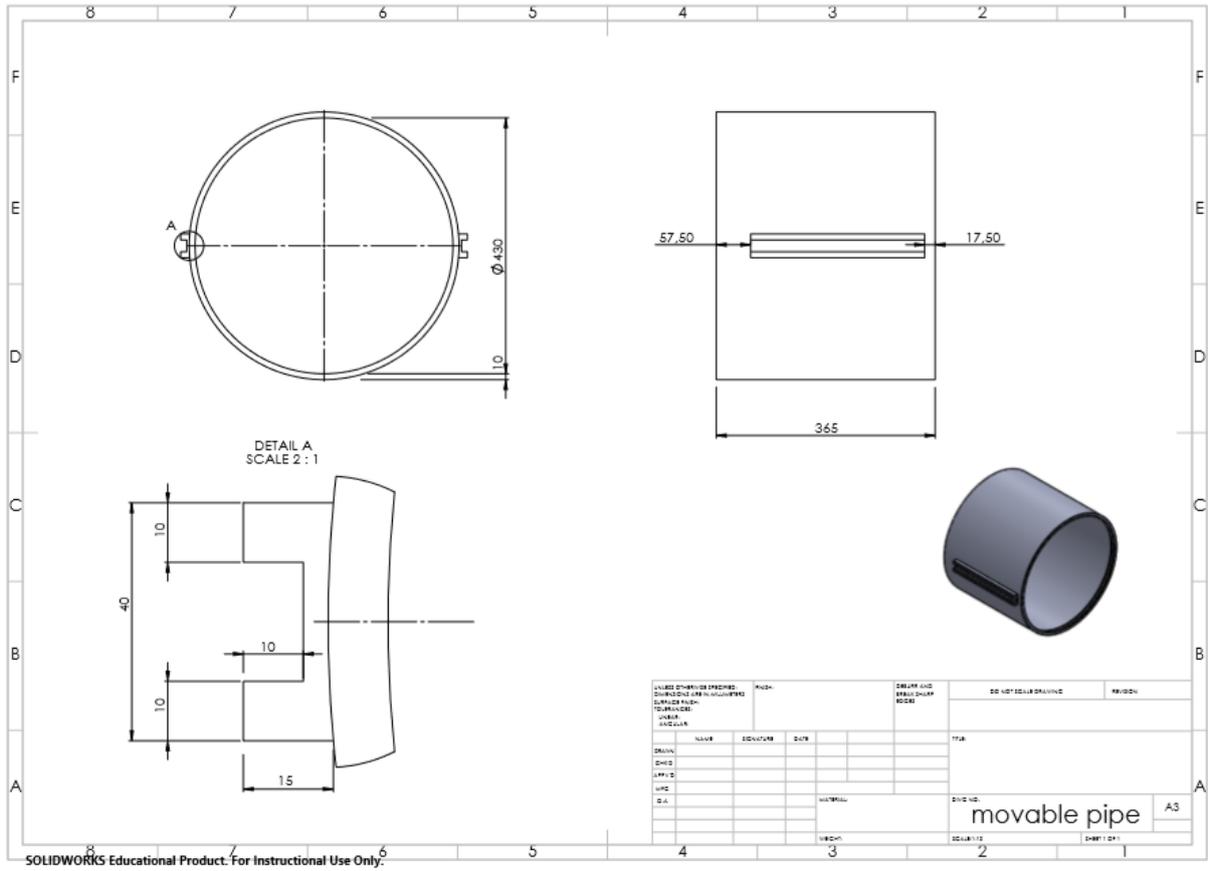
7 Attachment: 2D-drawing



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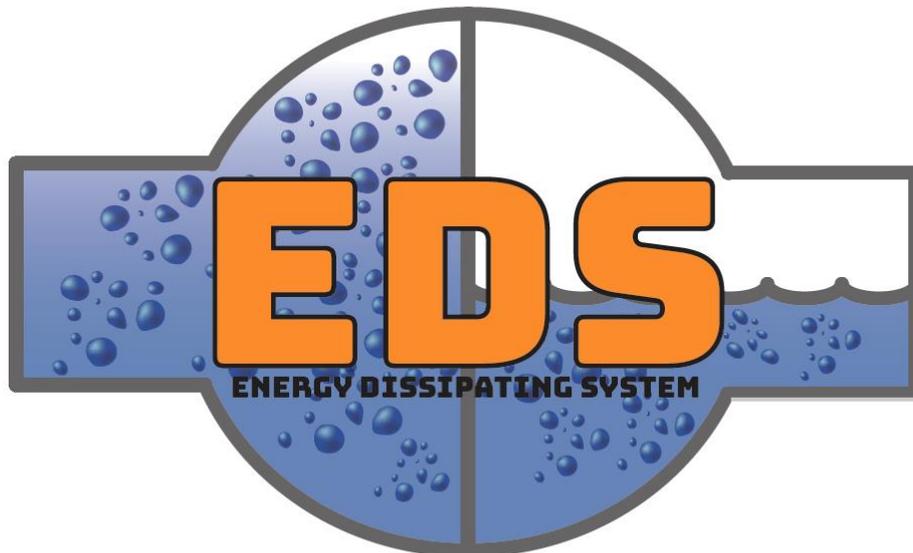


Multiconsult

Design of bypass valve

Technical document: Material

22.05.2018



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Abstract

Background: Material selection will be a part of the development of the selected concept.

Method: To evaluate the suitable material the group will start out by going through the fundamentals of different parameters that will be used in the selection. The most common materials in the valve industry will then be discussed and evaluated.

Result: Selected material for the parts of the valve body is: Main pipe, reinforcement block, and the flanges will be made of P355. The guiding block will be made from bronze, and the square sealing will be made from EPDM.

Selected material for the parts of the movable assembly is: The moving bracket will be made from 1.4401 stainless steel. The arm and the movable pipe will be made from 1.4023 stainless steel. Last, the movable sealing will be made from EPDM.

Selected material for the parts of the internal assembly is: The front cone and brackets will both be made from 1.4401. The perforated pipe will be made from 1.4023. Perforated pipe extension and separating wall will be made from P355.

Document history

Version	Date	Author	Description
0.00	16.04.18	OO	<ul style="list-style-type: none"> Created the document
0.01	17.04.18	LH	<ul style="list-style-type: none"> Added material descriptions
0.02	17.04.18	OO	<ul style="list-style-type: none"> Added Fundamentals
0.03	18.04.18	OO	<ul style="list-style-type: none"> Added discussion and selection chapter
0.04	19.04.18	LH	<ul style="list-style-type: none"> Rewrote material description and discussion into one chapter
0.05	24.04.18	LH	<ul style="list-style-type: none"> Finished the discussion and further improvements to the context
0.06	02.05.18	OO	<ul style="list-style-type: none"> Merged two “alloy” chapters Restructured “Discussion/selection” into “Material selection”
0.07	04.05.18	OO	<ul style="list-style-type: none"> Updated stainless steel materials
0.08	08.05.18	LH	<ul style="list-style-type: none"> Added introduction and rewrote some chapters to better convey the message
0.08	15.05.18	LH	<ul style="list-style-type: none"> Added valve seal material and selection
1.00	22.05.18	OO	<ul style="list-style-type: none"> Proofread Rewritten the abstract Changed reference setup Added references to Appendixes.

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1 Introduction

To make a product cost-efficient and viable for its application there are three key points, design, material choice, and production method. They depend on each other and needs to be developed with each other in mind. The designer can create a perfect design regarding fulfilling the stakeholder requirements, but if production method and material chose is not considered it may be too costly and in worst case not possible to produce. Different grades of steel may be better suited for certain production method and unsuited for others. For example, cast iron has a general low yield strength, but are accessible to machining and manufacture. Stainless steel has a higher yield strength and surface hardness but are more expensive to machine and unsuited to cast.

The group has evaluated the material possibilities in parallel with the design process and FEM analysis to simultaneous optimize the design and choose a cost-efficient material.

2 Theory / fundamentals/ parameters

In today's industry, there are numerous types of materials used for valve production. In essence, it can be boiled down to four groups which are iron, steel, plastic, and bronze. There also exists other metals and alloys used to accomplish the most effective design. Each material type has its specification, and one material does not fit them all. So how do we select the right material? In this chapter, the group will present different parameters taking into account when selecting a material. A brief explanation of the theory will also be presented.

2.1 Strength

The strength of a valve can be defined as being the ability to control the operating fluid under pressure (Johnson, 2008). In other words, when the fluid is flowing through the system, internal stress will be generated. There are several ways to measure the strength of a material, but the most common one is looking at the yield strength. Yield strength is the stress the material can withstand without permanent deformation. Ductility is also another factor that is considered. Ductility is defined as the materials ability to stretch slightly without any permanent changes. For example, cast iron is a material that has poor ductility. Materials with poor ductility are often defined as brittle materials. Brittle cast irons are mainly used in applications with low pressures, generally under 20 bar and where sudden significant changes in pressure don't occur. For higher pressure stronger, more ductile materials are used.

2.2 Fatigue

Fatigue is defined as the formation of micro-cracks when the material is exposed to repeated stresses and will decrease the yield and tensile strength of the material (Johnson, 2008). This can ultimately lead to fractures.

2.3 Corrosion

Another consideration in the selections of material is the corrosion resistance. Corrosion is the general name for the phenomena that causes oxidation of metal and can arise when the metal is in contact with water (Holmquist, 2017). The oxidation of steel which is caused by the combination of oxygen and iron results in rust and corrosion, commonly known as rust. This is an important parameter to be taken into consideration because the whole point of the system is to operate in water. Many materials are not stainless and will thus require a protective layer.

2.4 Erosion

Erosion can be a costly problem in valves where the fluid was defined as “clean” but in reality, contained small quantities of abrasive elements (Nesbitt, 2011, p. 205). These solid particles can in as little as weeks destroy the valve and prevent sealing on closure. Brian Nesbitt describes tests done on reciprocating pump valves (non-return valves which open and close continuously) that showed a doubling in valve material loss when exposed to 0.25% concentration of fine sand. In these tests, the velocity was only 2m/s. This will increase exponentially with the increase in velocity, and some research has shown that the erosion rate to be proportional to the velocity raised to the power of 2.5 minimum. In some cases, the power was found to be as high as 5.



Figure 109: Erosion in a choke valve caused by sand (University of Southampton, 2018)

Another source of erosion is cavitation. A detailed description of cavitation can be found in the *criterion analysis – cavitation* (see Appendix K). The cavitation can erode the valve or parts of the valve in a matter of weeks and make it unusable. It is thus essential to locate where the erosion will occur to choose the right material.

2.5 Availability

When choosing the material, the availability is closely related to cost. If it is an option, one should always select a material that is widely used. A typical, mass-produced alloy will always be cheaper than a custom-made alloy. The need for special custom-made alloys is when there is no other option to fulfill the requirements.

2.6 Production method

Another parameter that will affect the cost, as well as the quality, is how the part is manufactured. The materials characteristic and formability are highly dependent on the production method. Different production method may be cutting, extruding, welding, bending, casting and forging (P.Groover, 2010, s. 10). The two last ones, casting and forging, is the most common ones in the manufacturing of valves. Casted components are made from pouring melted metal into a shape and the machined if needed. Forging is a process where heated metal part is being shaped under the presence of high pressure in a press, like how a blacksmith work, but in a much larger scale. Forging results in better material characteristics compared to casting. The reason that this is not a more common production method in valve manufacturing is the cost. Casting is cheaper compared to forging and will in most cases achieve the required strength.

3 Parts

There are two “parts” in the valve. The valve body and the mechanism inside the valve.

3.1 Valve body

The valve body is commonly the largest single part of any valve. The valve body is constructed to withstand the operating pressure and to house the internal components of the valve. As mentioned the valve body is the largest part of a valve and the material cost will thus be more relevant. Valve body material is often specified after which material type the pipeline has (Valtek, 2018).

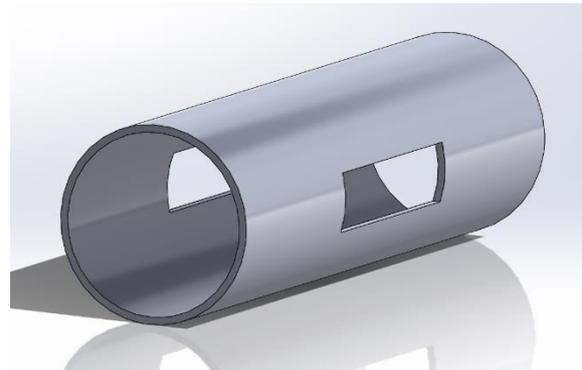


Figure 110: The valve body

Steel and ductile iron are two common materials used as pipeline material in larger hydropower plant. (Brødrene Dahl, 2018). One of the reasons for choosing the same material is due the fact that it may cause galvanic corrosion (Hobbs valve limited, 2013). Galvanic corrosion is caused by the difference in electrode potential in various materials, and the results will be that the material with the higher potential (anode) will corrode. Water with its presence of free ions can accelerate this process.

Looking at different ways of manufacturing, the group also see here that there are some common choices. A valve body can be cast, fabricated, forged or wrought. For most standard size and pressure ratings, casting is usually the first choice. For smaller valves with high-pressure ratings over 100bar forging are used. Seeing that requirements from our system we neither have a small valve or a valve operating close by the given pressure. Forging will most likely than not be an alternative. The valve will most likely be either cast or rolled.

3.2 Valve trim

The trim is defined as the “*Internal components of a valve in contact with the process fluid*” (Nesbitt, 2011, p. 38). In other words, they are the parts responsible for controlling the flow rate and is subjected to the most significant amount of forces. The material in the valve trim is selected with regards to its resistance to abrasion and cavitation, I.E. they resist wear and galling. An exception to this is the valve seat, here soft, non-metallic materials should be used if it is necessary to have a leak-free valve (Nesbitt, 2011, p. 319). In general, the material in the trim is often more resistant to corrosion, has a better surface finish and a higher tensile strength than the valve body.

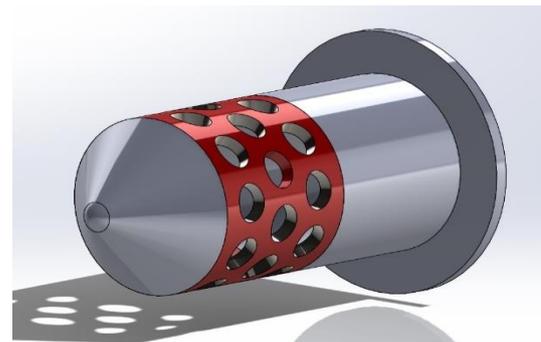


Figure 111: The valve trim

3.3 Sealing

The sealing is described in depth in the in the design document (*see Technical document: Design*)

4 Material description and discussion

In this chapter, the selection of materials will be determined. The selection process will be split into two parts. The first part contains a discussion in each of the material groups, for example, PVC, brass, cast iron or stainless steel. After the discussion, the best material group for our valve will be selected.

The second part is selecting the alloy of the material group chosen. There are hundreds of different alloying composition within each group, and each one with slightly different properties and specializations (Masteel, 2018). For example, the P355NH is for moderate to high temperatures, and P355NL1 is for ideal use in low temperatures.

This process will be done for both the valve body and the valve trim. The valve trim is subjected to the most substantial amount of both abrasive forces and flow, and will thus need a material with higher surface hardness than the valve body.

4.1 Valve materials

The following materials are some of the most common used in valves.

4.1.1 PVC and plastics

PVC and other types of plastic valves have one major advantage, they are cheap to produce and has a excellent, natural corrosion resistance. (Johnson, 2008). They are also lightweight and thus easy to transport and install. However, the downside to plastics is that they have a low maximum operating pressure. For example, polyvinyl chloride (PVC) grade 1 type 1. In a temperature of 24°C the operating pressure is about 10 bars. For our application, this is way too low as our operating pressure is up to 30 bars



Figure 112: 3-way PVC ball valve (Irrigation Express, 2018)

4.1.2 Brass and bronze

Next materials that will be evaluated is the copper alloys bronze and brass. These materials are an “upgrade” over plastic valves and can withstand higher pressures and temperatures (Dickey, 2014). The price of brass and bronze valve is more expensive than plastics, but still relatively cheap.



Figure 113: Bronze valve (Albion Valves, 2018)

Brass is a mixture of copper and zinc and is considered to be one of the more softer metals in the valve industry (Dickey, 2014).

Bronze, on the other hand, is a mixture of copper and tin. The material is harder, but more brittle compared with brass. When evaluating the material characteristics, the group see that both of the materials has a high corrosion resistance. Brass and bronze valves are usually used in low/medium pressure services. Most of them operate in pressure under 30 bars, but some may also top 40 bars. Seeing as the pressure class that the group works with is PN40, this could be an opportunity. The copper alloys that can withstand the given pressure will most likely have a price closer to other materials with more favorable

characteristics. The operating pressure for the given materials is also concerning, even though it can withstand the requirements a safety factor may be relevant.

4.1.3 Iron and steel

The most common material used in larger valves is usually some alloy of iron. According to EN-10020, “*steel is defined as a material, where the weight percentage of iron is higher than that of any other element, and carbon content is less than 2%*”. Some of the most common alloys of iron is described below and at the end there will be a general discussion of iron used as a valve material.

4.1.3.1 Cast iron (BS 1452, ASTM A126)

Cast iron is a relatively cheap material and is mostly used for valve bodies for water, gas and other non-corrosive fluids (Kitz Corporation, 2018). It is easy to cast and to produce more complex castings including thin sections. It is also easy and decent to machine (Nesbitt, 2011, p. 316). The cast irons generally have low corrosion resistance and tensile strength and are not suitable for applications where the fluid is corrosive or when the operating pressure is high.

4.1.3.2 Ductile cast iron

With the addition of nodule-shaped graphite, cast iron will become more ductile so that it will become less brittle (Commercial Industrial Supply, 2017). The maximum temperature will decrease, but the pressure remains almost the same. Ductile cast iron is more expensive than regular cast iron.

4.1.3.3 Cast steel (BS 1504-161 grade 480, ASTM A216WCB)

This is the most popular valve material and is used for air, saturated and superheated steam, non-corrosive liquids and gases (Nesbitt, 2011, p. 316). Although the cost is about four times as high as cast iron, the addition of alloying elements can increase the pressure and temperature rating far beyond cast iron. It is not the easiest material to cast and can be prone to tearing when machining.

4.1.3.4 Chrome-molybdenum steel (BS1504 625, ASTM A217 Grade C5)

It is a popular alloy in a wide range of applications in construction and manufacturing (Nesbitt, 2011, p. 316). It has a high tensile strength and can withstand temperatures up to 593°C. Regarding valves it is mostly used with corrosive fluids (high-pressure steam, oil, petroleum vapor, seawater). The cost is somewhat greater than cast steel, but it is stronger at higher temperatures.

4.1.3.5 Stainless steel (AISI 316, BS 1504-316C16, ASTM A351 CF8M)

Stainless steel is especially suited when oxidizing and very corrosive fluids is used (Nesbitt, 2011, p. 316). It can withstand temperatures up to 800°C. However, this means that the cost is about two times greater than Chrome-molybdenum steel. It can be challenging to cast and machine and requires heat-treatment after production.

4.1.3.6 Carbon steel (P/S 235, P/S 355)

These are alloys has wide range of uses where the S prefix is for construction and general use, and the P prefix is for pressure purposes (Steel tube, 2011). They are defined in the EN-10020- series. The pressure series are the most relevant to be used in our valve. Within the P prefix there are several different configurations, such as:

- T - steel for tubes (T - tube)
- R - ambient temperature (R - room temperature)
- H - high temperature
- L - low Temperature
- N - normalized or formed

The finished name for the metal will be for example P355TR, which is a steel for pressure applications with a minimum yield strength of 355 N/mm² and is specialized for tubes at room temperature.

4.1.3.7 Discussion

Iron and steel have in general higher tensile strength than the materials listed until now. The corrosion resistance is also respectable in some alloys and with surface treatment.

Compared to the other materials it has much higher yield strength than plastic and is more wear resistant than brass and bronze.

The two types of iron that are the most relevant for us is carbon steel and stainless steel.

- Carbon steel is a mixture of carbon and iron. The Material has excellent mechanical properties with its fatigue strength and high/ low-temperature strength. Carbon steel is usable in a large variety of pressure classes. Carbon steel valves can hold pressure up to 400 bars and more. Adding some other types of alloying elements can give a higher corrosion resistance. Corrosion resistance is the main difference between carbon- and stainless steel.
- Stainless steel is an iron alloy containing a mixture of iron, chromium, and nickel (Dickey, 2014). The composition makes the metal extremely corrosion resistance and durability. The material is used in a wide spectrum of application. Everything from petroleum industry, chemical industries and also hydropower plants. The downside with these materials will be cost, which is more expensive compared to ductile iron. This corrosion resistance is not needed in the valve body but is very relevant in the valve trim.



Figure 114: Globe valve made in cast steel (VI Consulting, LLC, 2018)

4.2 Sealing materials

There are many different sealing materials, and only the most relevant for the bypass-valve will be covered.

4.2.1 Flax

A natural fiber which has limited chemical resistance. When braided the flax can operate under temperatures ranging from 0 to 90 °C and under pressures up to 80 bars (Nesbitt, 2011, p. 272). Applications are normally limited to water and seawater.

4.2.2 PTFE (Teflon)

It has a wide temperature range from -100 to 280°C and is efficient in pressures up to 140 bars (Nesbitt, 2011, pp. 273, 276). Special braiding techniques combined with die-forming can increase the maximum pressure up to 250 bars and graphite lubricated PTFE can withstand pressures up to 350 bars. PTFE is also self-lubricating which mean the sealing can run dry with little increase in wear.

4.2.3 EPDM (Ethylene propylene diene monomer)

EPDM is a cost-efficient synthetic elastomer. It is used in a wide range of application such as vehicles, equipment, and valves (AZO materials, 2018). EPDM main advantages are that it resists sunlight, water, aging, acids and severe weather conditions. It also provides high heat resistance, with service temperatures ranging from 70°C to 250°C. It also has elasticity combined with good tensile strength, typical in the ≈68 bar range. Elasticity is around 300%. EPDM also has a higher resistance to abrasives and cutting compared to silicones and thermoplastic and nitrile elastomers. The main disadvantage with EPDM is the unsatisfactory resistance to some chemicals such as diesel fuel, motor oil, gasoline and synthetic diester oils.

4.2.4 Natural Rubber

It used to be the most popular elastomer because of its resilience, low-temperature properties and wide range of hardnesses (Nesbitt, 2011, p. 274). Very good for gases and water. Humanmade polyisoprene has taken over for the natural rubber as the most popular elastomer as it has almost identical properties.

5 Material selection

5.1 Sealing material

The sealing material that will be used is the EPDM. This decision is based on the positive factors of the EPDM, and that the negative doesn't impact the bypass valve as the fluid is water (VAG, 2018). EPDM is also a commonly used valve material such as the VAG RIKO® Plunger Valve.

5.2 The valve body and reinforcing blocks

In the last chapters, typical materials used in valve manufacturing has been discussed. The materials strength, corrosion resistance, and cost have been evaluated. One of the objectives of the project is to produce a product that has the possibility to compete with other products when it comes to the price. Even though the cost is a focus, the concept first need to withstand the operating environment. To exclude some materials when it comes to the strength some tables will be presented.

The first table to be presented is a table showing working pressure and temperature range for different valve body materials. In this case, the pressure will be the decisive parameter. The table is provided by a valve manufacturing company called Kitz. The company is a world's leading company in this area. Because the fact that the source is specialized in valves the group considers the information to be reliable.

Working Pressure & Temperature Range for Valve Body Materials

Body material	Max. permissible pressure (MPa)							Permissible temperature range (°C)						
	0	2	4	6	8	10	12	14	-200	0	200	400	600	800
Gray cast iron														
Nodular graphite cast iron														
Ductile iron castings														
Carbon steel castings for high temperature / pressure service														
Stainless steel castings														
Bronze														
Brass														

Figure 115: Working pressure and temperature range for some materials (Kitz Corporation, 2018)

The table presents the max permissible pressure and temperature in each of the materials. It should be noted that these numbers are an estimate, and the real permissible pressure is dependent on design factors like wall thickness and pipe diameter. The valve must be designed within PN40 which is a pressure class. This means that the valve must operate under a pressure of 40 bars or 4 MPa. Therefore, the relevant materials are either carbon steel or stainless steel.

Carbon steel is probably the most common material in valves, and it is ideal for non-corrosive liquids (Skousen, 1997, pp. 50, 51). It is widely used for steam and condensate services and does exceptionally well in high temperatures, up to 425°C in continuous service. It is widely available and is generally inexpensive compared to other commonly used metals.

Stainless steel is very corrosion resistant and is commonly used in high-temperature applications at around 535°C and higher. It is more expensive than carbon steel.

Since our working fluid is water at temperatures ranging from 0 to 20°C the material does not require high-temperature resistance. The fluid is also not corrosive so the best material for our applications will be carbon steel.

5.2.1 Choosing the alloy

As mentioned there are numerous different alloys within each metal “family”. Before the valve can be parametrized and tested in FEM the specific alloy needs to be specified. To do this, the group will use European standard (EN) to find the relevant alloys and their specifications. For the valve body, the production method also needs to be defined. Carbon steel can be cast, forged and produced in many other ways, and for each production method a different alloy is the best.

After consulting with Multiconsult, there are two series of carbon steel in EN-10020, the S- and P series. There is no requirement for either low or high temperature, the only thing is that the material must withstand the operating pressure. The P-series is the best for our valve since it is specified for pressure applications. To find the required yield strength the group must do some calculations. The pressure that is used in these equations is the specified pressure from the PN40 pressure class, which states that the system must operate under at least 40 bars.

Barlow's formula $P = \frac{2St}{D}$, for calculating the maximum pressure in a pipe.

- P is the maximum pressure in the pipe at yield strength in Mega Pascal (MPa)
- S is the yield strength of the material in MPa
- T is the wall thickness in meters
- D is the outside diameter in meters

If we rewrite Barlow's equation with respect to S we get $S = \frac{PD}{2t}$ and with the relevant parameters calculated in the Design-document inserted, the minimum yield strength at the maximum operating pressure is:

$$S = \frac{4 * 0.7}{2 * 0.0214} \approx 65 \text{ MPa}$$

With a safety factor of 3 the material must have a yield strength of at least 196 MPa. The P235 family has a yield strength of 235 MPa and is the lowest grade specified in EN-10028. This alloy is therefore best suited for the valve body. It should be noted that this calculation is for a solid pipe and our valve has slots for the control mechanism that will create weakness in the body. The valve body material is therefore subject to change.

5.2.2 FEM analysis results

From the FEM analysis (*described in the Technical document: FEM*), the forces around the slots in the valve require that the material is a higher grade than P235. P355 is the best choice, as the yield strength is sufficient.

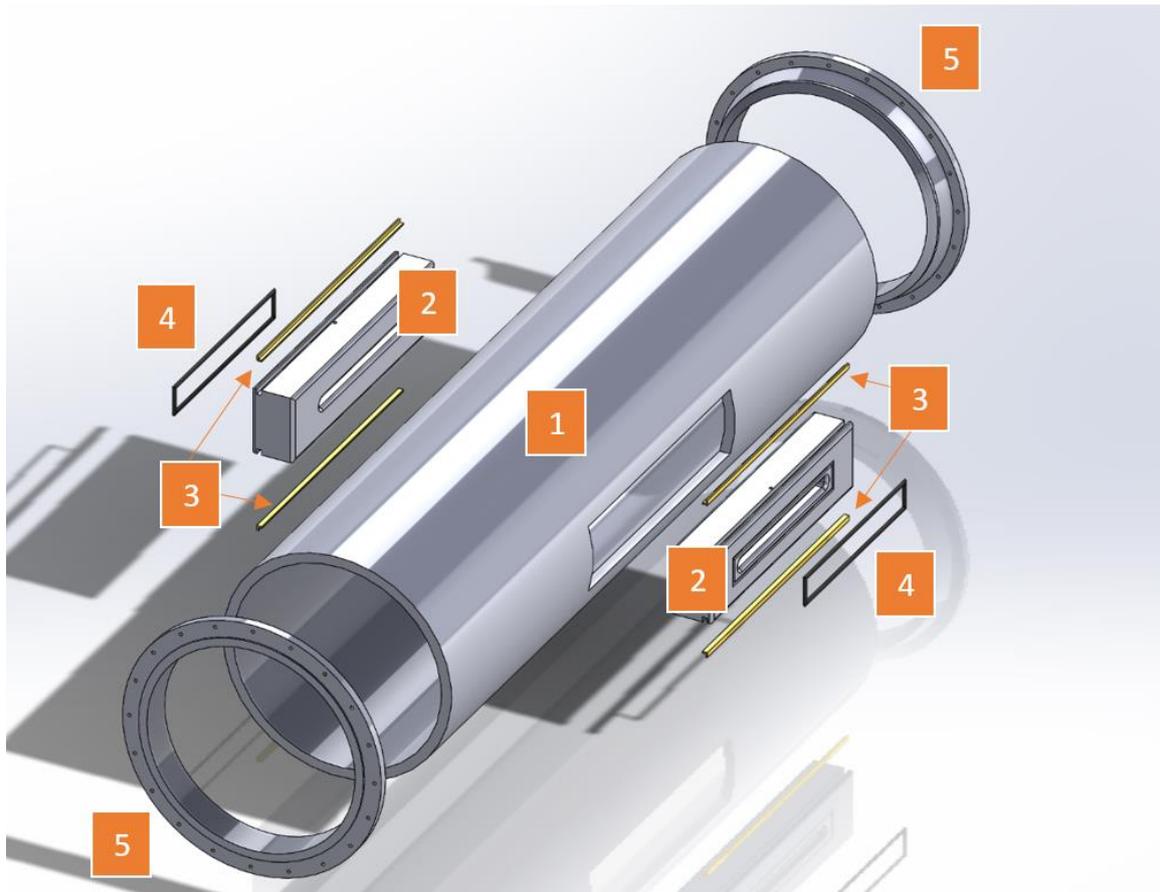


Figure 116: Valve body and associated parts material description

Part No.	Material ASME	Material ISO
1	A537	P355
2	A537	P355
3	Bronze	
4	EPDM	EPDM
5	A537	P355

Table 20: Valve body and associated parts material description. The part numbers are explained in the figure above

Part No. 1, 2 and 5 will be in the same material, P355. Part No. 3 is the gliding blocks that will help reduce the friction when the control mechanism moves. Part No. 4 is a Teflon based sealing.

5.3 Valve trim

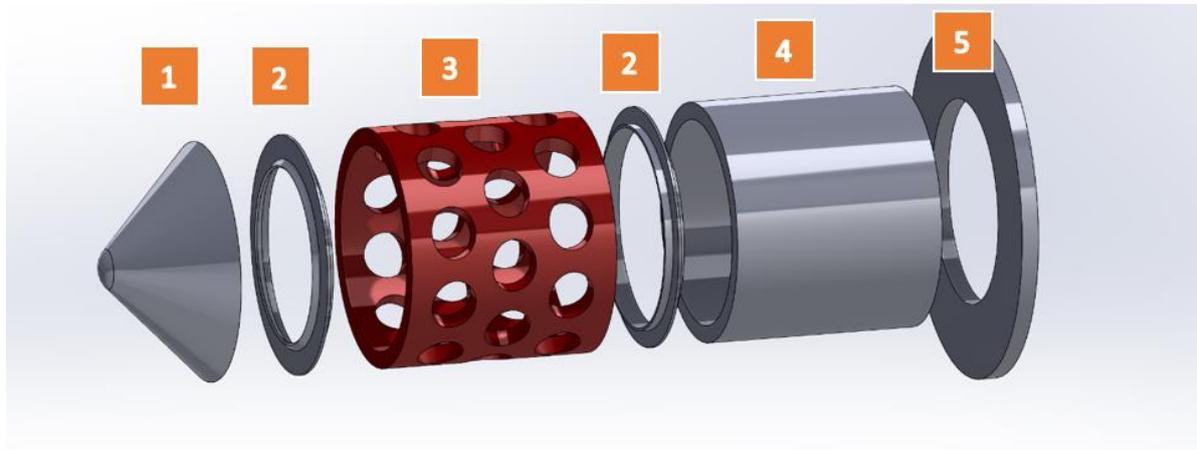


Figure 117: Valve trim parts

Part No.	Material ASME	Material ISO
1	316 Stainless steel	1.4401
2	316 Stainless steel	1.4401
3	440C Stainless steel	1.4023()
4	A537	P355 Carbon steel
5	A537	P355 Carbon steel

Table 21: Valve trim material description. The part numbers are found in the figure above

Part No. 3 is subjected to the most amount of abrasive forces and must thus be manufactured in a material that has high hardness. Part No. 1 and 2 is not subjected to the same kind of abrasive forces but is still in a potential high flow area with a chance of abrasive particles. Part No. 4 and 5 is evaluated to be in a zone with low amount of abrasive particles and should ideally be created in the same material as the valve body as they will be welded to the body.

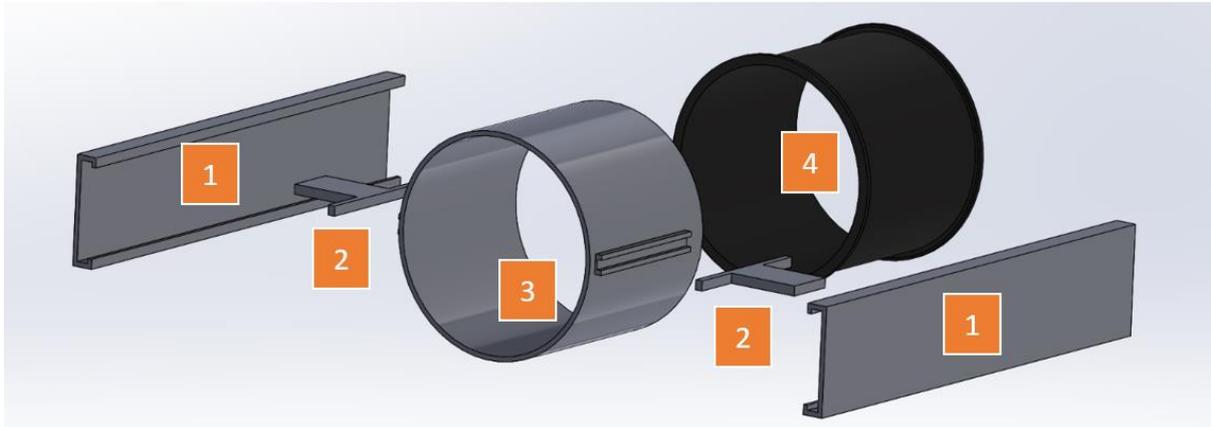


Figure 118: Control mechanism parts

Part No.	Material ASME	Material ISO
1	316 Stainless steel	1.4401
2	440C Stainless steel	1.4023()
3	440C Stainless steel	1.4023()
4	EPDM	EPDM

Table 22: Control mechanism material description. The part numbers are found in the figure above

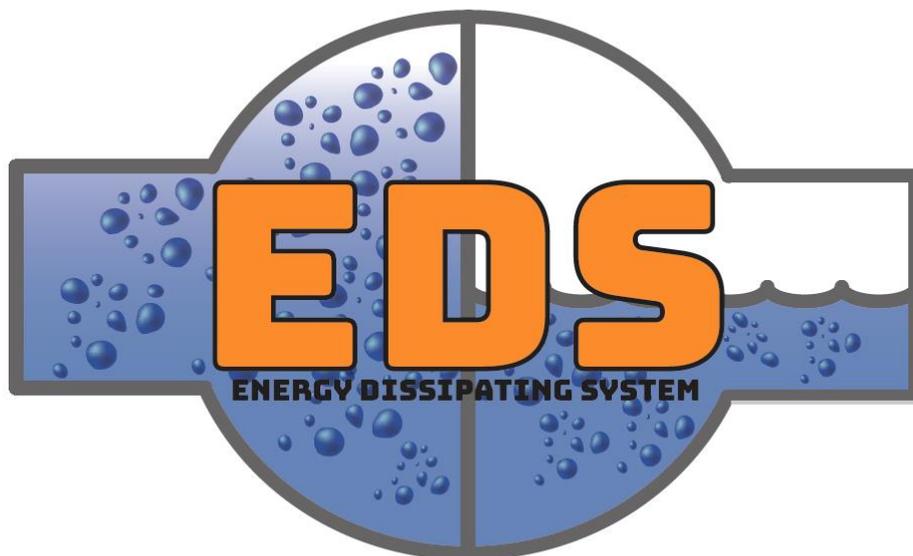
Part No. 3 is subjected to the most amount of potential abrasive forces and will be created in a material with high hardness. Part No. 2 requires a material with a high yield strength as the arms are quite thin and need to be strong enough to move the sleeve. Part No. 1 also needs a relatively high yield strength since the part will seal the valve. Part No. 4 is the valve seat sealing and is to be created in a Teflon based sealing, either with Teflon-rubber or some other kind.

Multiconsult

Design of bypass valve

Technical document: Flow optimization

22.05.2018



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Abstract

Background: Flow optimization is the analysis of flow done in the optimization of the concept in the construction phase.

Method: To acquire the final dimensions of the product, an incremental approach is used. The main tool used to analyze each increment is ANSYS Fluent. Through these increments, the analysis has been adapted to the development of the design process. If a simulation failed, the design would have to be changed. The objective of this process has been to modify the product to fulfil the requirements.

Results: After four increments, the final concept includes the modifications from this and the other technical areas. Following the numerical results, the concept fulfils the requirements related with the flow. However, an experimental validation would be needed to verify the numerical results.

Document history

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1 Introduction

After the setup of a model (see *Appendix L*) the input parameters can be modified to acquire different solutions. The system requirements define these parameters and variations. The parameters affecting the flow optimization is the input parameters which consists of geometrical dimensions and flow properties, such as pressure and velocity. These parameters are modified in order to find the optimal values which fulfill the requirements and improve the performance of the final product.

During the optimization process, the simulations have been constrained by the needed time related to the computational capacity. There is also a concern related to the accuracy because of limitation in the academic license in the program.

The approach to solving all the questions coming from the design optimization has been faced through incrementally improving the design. An increment is defined as a stage in the design process where the model fulfills an intended goal. By going through several of these stages, the system will incrementally improve and eventually fulfill all the system requirements.

This document is strongly related with the *CFD document*. Both go through increments as an approach for integrating the design changes coming from the different technical analyses. It can be confusing that the *Technical document: Design* uses six increments until the product acquires its final configuration and this document has only four. The configurational design encompasses all the technical areas to make the final product, so it changes under any variation of any analysis. However, the flow analysis is not affected by all the changes, e.g. the changes in the external mechanism does not affect the flow analysis because they are out of the pipe. Therefore, a unique iteration of the flow analysis can correspond to several iterations in the *Technical document: Design*. The references between the iterations are explained in each iteration.

2 Objective

The objective of the flow optimization is modifying the design to ensure the fulfillment of the system requirements related to flow (see *Appendix A*). While the other areas work to fulfill the other requirements, and everything is encompassed to find the optimal final product.

Requirements linked:

2.1 RQ-1

“The system MUST operate under the pressure of 100- to 300-meter water column.”

2.2 RQ-2

“The system MUST operate with a flow rate up to $3 \text{ m}^3/\text{s}$ ”

2.3 RQ-3

“The system MUST have a predictable flow characteristic”

2.4 RQ-4

“The system MUST manage cavitation satisfactorily”

2.5 RQ-5

“Maximum velocity in the pipeline MUST not exceed 10 m/s”

3 Parameters

During the optimization process, several models has been prepared and run for different purposes. The concept of operation defines roughly the shape of the product. Therefore, the exact dimensions are the objective of this optimization. These dimensions are defined as the input parameters of the models.

The link of the simulation results and the requirements is defined by the output parameters, except the RQ-1, which is defined as an input parameter in the *Pressure at the inlet*.

Input parameters	Units
Inner cylinder length	m
Inner cylinder radius	m
Number row of holes	-
Number of holes per row	-
Holes radius	mm
Angle of the holes walls	Degree
Thickness of the valve body	mm
Angle of the connection between the inner part and the pipe	Degree
Pressure at the inlet	bar
Opening grade	%

Table 23: Input parameters of the flow analysis

Requirement	Output parameters	Units
RQ-2	Volume flow rate	m ³ /s
RQ-3	Volume flow rate	m ³ /s
RQ-4	The average volume fraction of vapor in the hole walls	m ³ / m ³
	The maximum volume fraction of vapor in the walls of the hole	m ³ / m ³
	The minimum volume fraction of vapor in the hole walls	m ³ / m ³
	The average volume fraction of vapor in the valve wall after the hole	m ³ / m ³
	The maximum volume fraction of vapor in the valve wall after the hole	m ³ / m ³
	The minimum volume fraction of vapor in the valve wall after the hole	m ³ / m ³
	Minimum mass transfer rate in the hole walls	kg/ m ³ /s
	Average mass transfer rate in the hole walls	kg/ m ³ /s
	Minimum mass transfer rate in the walls after the hole	kg/ m ³ /s
	Average mass transfer rate in the walls after the holes	kg/ m ³ /s
RQ-5	Maximum velocity at the outlet	m/s

Table 24. The relation between the requirements and the linked parameters

3.1 RQ-1 parameters

This requirement is ensured by setting it as an input. The software has the possibility of defining the inlet boundary condition as a pressure inlet, in which the pressure was fixed to 30 bar, equivalent to 300-meter water column.

3.2 RQ-2 parameters

The volume flow rate can be measured in any section of the pipe, and it must be the same in every section. The volume flow is defined as 3 cubic meters in the inlet when there is a 100% opening.

3.3 RQ-3 parameters

The group has measured it by the parameter volume flow rate and the opening grade (see Appendix J). Changing the opening grade from 0% to 100%, with several intermediate points, and measuring the volume flow rate in each of them we obtain the flow characteristic.

3.4 RQ-4 parameters

The cavitation, even in the real world, is much more difficult to measure than the rest of the parameters (see Appendix K). For this, the group has used to variables: the volume fraction of vapor and the mass transfer rate.

- The volume fraction of vapor is the volume relation between vapor and liquid in a biphasic mixture. 1 means complete vapor and 0 means complete liquid.
- Mass transfer rate: it is not a real mass transfer rate, as it is explained in the mass transfer theory, but it is called like this due to the way Fluent calculates the cavitation. It means the mass per unit of volume which is changing of phase per time unit. If it is positive means that the liquid is getting into vapor, and if it is negative it means the vapor is transforming into the water, and therefore, cavitating.

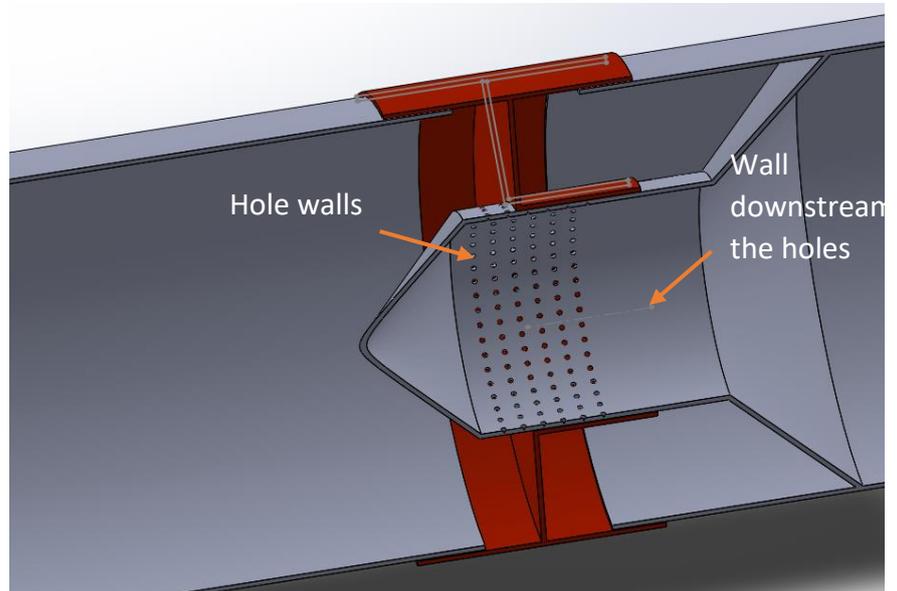


Figure 119. Moveable Pipe 3 CAD model

As the group is concerned about the cavitation occurring close to solid surfaces, the parameters defined are referred to the surfaces where cavitation could be expected: walls of the holes and walls of the valve downstream the holes, detailed in Figure 119.

For a more accurate measurement of these parameters, the group has defined several parameters in these surfaces. For both parameters, the average, the maximum and the minimum value of them has been calculated in the surfaces.

3.5 RQ-5 parameters

The maximum velocity at the outlet has been measured to ensure the requirement fulfillment. The reason for choosing the outlet for measuring the maximum velocity is that the requirement is referred to the main pipe at a normal flow. The flow close to the valve is disturbed, due to the changes in direction and velocity inside the valve. In the model, the outlet has been set far away from the disturbed part. Therefore, the flow gets normalized at that position.

4 Validation of the results

After the setup of the flow analysis, the solver is run to acquire a solution. The numerical process of the solver can be monitored. This monitoring provides information about the development of the solution of the system of equations. This is only a mathematical process, the convergence of the solver does not mean good results as they can be non-physical. To verify the results, some physical values must be measured as well.

4.1 Non-physical results

The first measurement for the CFD engineer is looking at some plots of the results and judge them. If some non-physical results are found the simulation is not valid. Although the plot of the variable of interest is alright, it can be influenced by the other variables. So, every important plot must be all right. It is very inefficient to verify every single variable at each simulation, so the CFD engineer should locate the critical ones and verify them.

The group has an example of non-physical results in the Figure 120. It is a detail view of the outlet pipe of the valve. The velocity direction is defined by the vectors and the magnitude by the colors. In the middle of the pipe, there is a section where the water goes in opposite directions at the same time, which is impossible. The water is disappearing in this section.

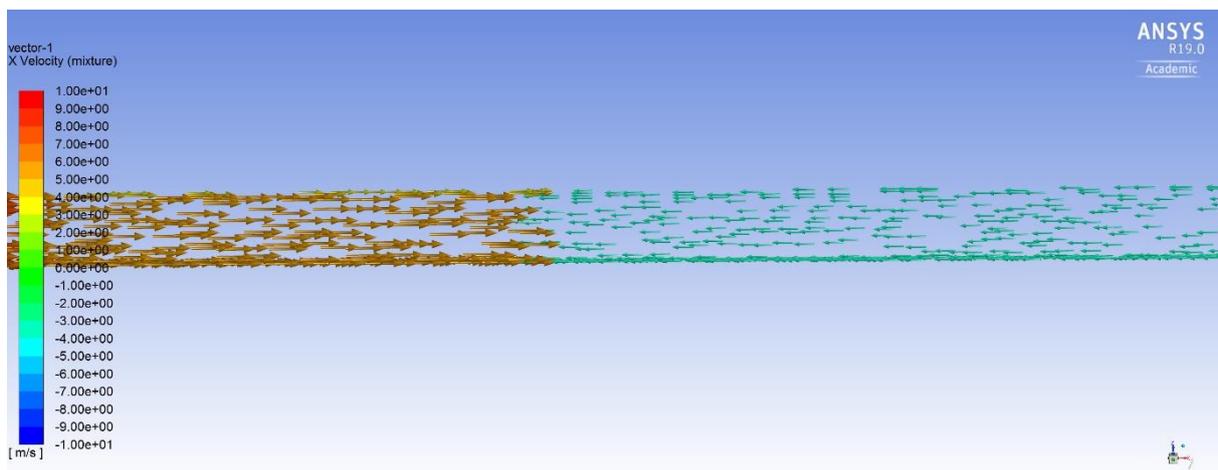


Figure 120. Example of non-physical results from a simulation in Fluent in a section of the outlet of the valve

4.2 Mass conservation

Apart from the verification of the plot, the simulation can be automatically verified making some simple balances. In our simulation, the group has made a mass balance through the system. This balance consisted in making the relative difference of the mass

flow rate in the inlet and the outlet. Making this, the group validates the overall mass conservation throughout the system. The general criterion is maintaining this value as low as possible, but never over a 0.1 % of difference (see *Appendix L*). The results of the most critical simulation are in Annex 2.

4.3 Time dependency

All the simulations of this project are steady-state. This means that they have no dependency on time. This is a hypothesis and must be verified. The group ran transient analyses for every model to verify so. The objective is looking at the result and proves that the transient solution doesn't vary along the time. This was right for every model.

4.4 Fluid properties assumptions

During the definition of the fluid properties in the setup, the group assumed every fluid as incompressible. The liquid water is well-defined as incompressible in every situation. However, the water vapor is a gas and this assumption can be wrong. The criterion used for the correct assumption was keeping the Mach number under 0.3, which means a maximum velocity of $119,1 \text{ m/s}$ (see *Appendix L*).

$$M = \frac{u}{a} \quad (1)$$

The maximum velocity in the simulations has never reached 100 m/s , so the incompressible assumption is right.

5 Optimization process

In this section, the objective, development and results of the flow analyses are explained and discussed (see *Appendix L*). Through the incremental approach, the group has updated the inputs and the outputs of the simulations to adapt them to the design process.

5.1 First increment

5.1.1 Model

The first increment model derives from the concept phase. A parametric CAD model was designed with the dimensions listed in Table 24, simplified by the circular symmetry.

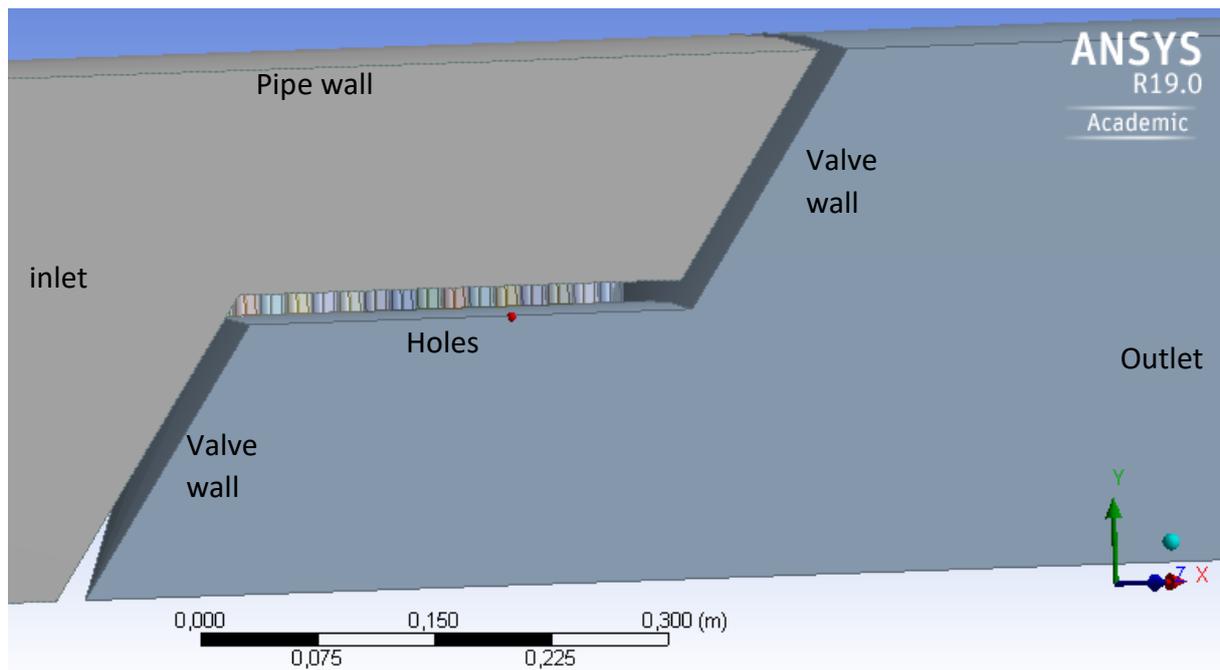


Figure 121. CAD model in ANSYS DesignModeler of the complete valve. In this model the 3D objects are the fluid domain

In this simulation, all the physical equations presented in the setup were included: flow, turbulence, and cavitation. Therefore, the simulation involved every single characteristic of the problem and gave accurate results. However, it meant a more complex and time-consuming, as it was solving every aspect of the problem at once.

5.1.2 Solution process

This model captures the complete performance of the valve. However, it meant a more complex and time-consuming calculation, as it was solving every aspect of the problem at once.

The complexity of the simulation made the solution process unstable and tended to diverge. This divergence was caused when trying to calculate the cavitation. The mesh was refined several times for a better definition of the strong variations in velocity and pressure in the holes, as well as the cavitation. Then, the limit of cells of the academic license was reached several times before acquiring a good solution. An insufficient number of cells gives an inaccurate solution. Moreover, In CFD analyses this could result in a problem impossible to solve.

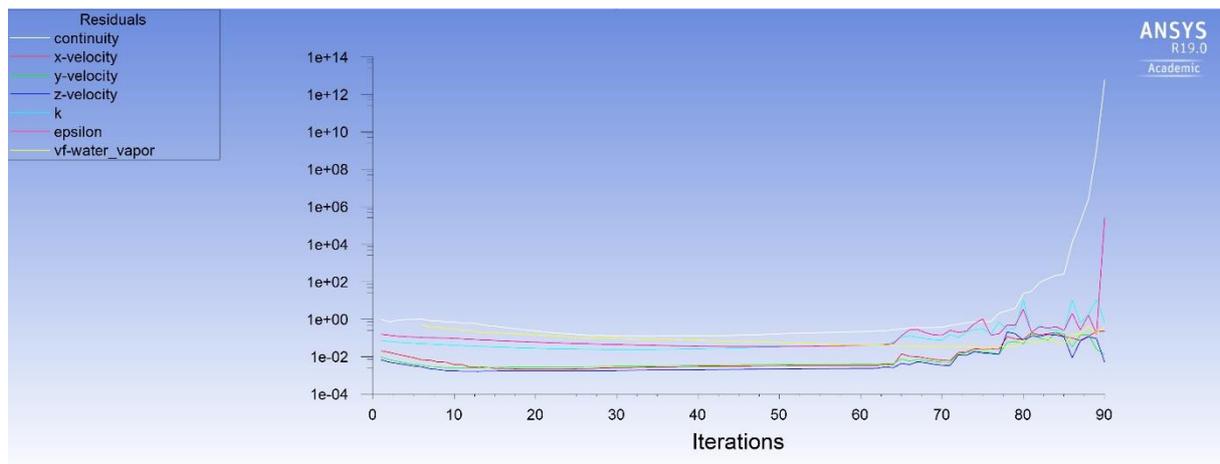


Figure 122. Variation of the residual during a simulation which ended in divergence

In Figure 122, there is a picture of the residuals in a simulation which included cavitation. The residuals mean the relative accuracy of each iteration of the solver, their value is in the vertical axis. As we can see, they went to high numbers, which means complete loss of accuracy.

5.1.3 Results

The results were difficult to get, and most of them were non-physical due to the divergence. Only results with low velocity were able to converge, but this meant RQ-2 is not fulfilled.

5.1.4 Conclusion

With our knowledge in CFD, the educational license limit is too low for us to perform this simulation. Also, the computational time required makes this approach excessively slow for an iterative process. Considering the multiple areas involved, a faster tool is needed for a better develop of the design process.

5.2 Second increment

After the adverse results of the first increment, the group decided to divide the simulation into two different CFD models: one for simulating a single hole with the cavitation, and the other with the complete valve but without cavitation.

This approach enabled the group to design the shape of the holes to minimize or optimally avoid cavitation. Moreover, the group could integrate this shape into the complete model and get the configuration which fulfills the rest of the requirements.

5.2.1 Hole model

5.2.1.1 Model

The group created the 2D axisymmetric model explained in the document (*see Appendix L*) we can see it in Figure 123. Although this model differs significantly from the real one, especially in the flow direction, it has been chosen due to its simplicity. In the real model, the direction of the flow is perpendicular, and in this model is parallel. The reason of simplifying that much the model is for achieving an axisymmetric model, which can be

transformed in to a 2-dimensional model. Two dimensional models are much less time consuming than 3-dimensional models.

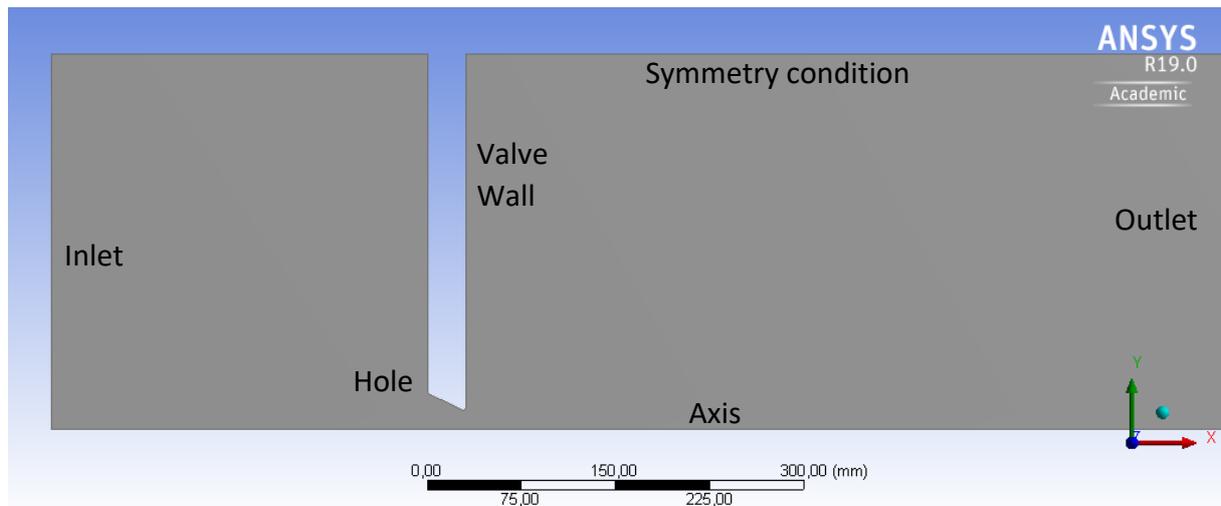


Figure 123. Detail of the geometrical model of the simulation of a simple hole

For facing the optimization of the shape of the hole, the group decided to make the holes conical. The election of the conic shape was for having the lower pressure at the end of the hole, instead of all along the hole. And having the maximum velocity in the same position, it is expected to avoid the cavitation close to surfaces.

By changing the conic angle and the inlet radius of the holes, its relationship with cavitation will be captured. The wall thickness was decided in the design process (see **Technical document: Design**) where calculation was made by using the selected material (see **Technical document: Material**).

Input parameters		Output parameters	
Variable	Variable	Where	What
The thickness of the wall	The volume fraction of vapor	Holes walls	Average
The angle of the cone			Maximum
Hole inlet radius			Minimum
		Walls downstream the holes	Average
			Maximum
			Minimum
	Mass transfer rate	Holes walls	Minimum
			Average
		Walls downstream the holes	Minimum
			Average

Table 25. Input and output parameters of the simulation of a single hole with the cavitation model.

5.2.1.2 Solution process

Due to the cavitation effects, the model is more complex, and so, more unstable and time-consuming. The solution was reached by running the model with a Segregated Solver and setting the sub-relaxation factors related with the cavitation: density, volume fraction and vaporization mass, under 0.001 to provide stability at the beginning of the calculation. The group used dynamic mesh adaption to optimize the mesh. The regions where the gradient of velocity was over the 50% of the maximum were refined and reran. Then, the action is repeated but with the volume fraction of vapor to acquire a more accurate definition of the cavitation.

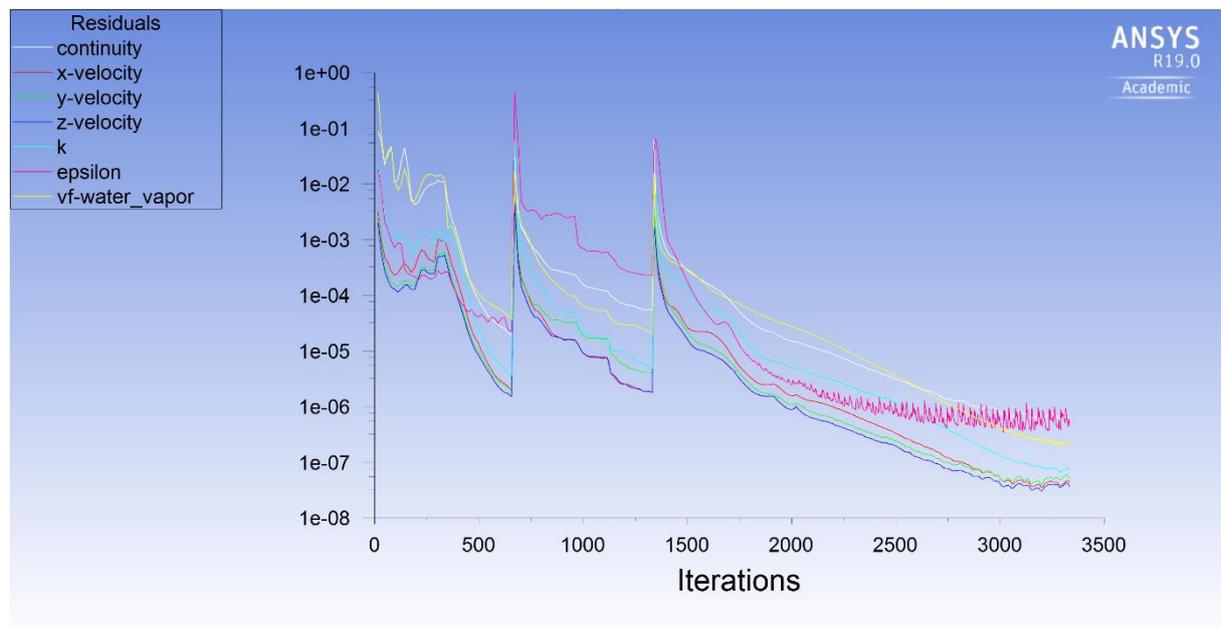


Figure 124. Residuals during a simulation of a hole with the cavitation effects. The two intermediate high points correspond to the mesh refinements

In Figure 124, there is a picture of the residuals during simulation with cavitation. The two intermediate high points correspond to the refinements of the mesh. Finally, the convergence was reached

Several simulations were queued varying the non-fixed input parameters and saving the output ones. The result was the definition of its relationships.

5.2.1.3 Results

The group used Excel to analyze the results of all the calculations. Moreover, after the analysis, we saw a strong relationship between the angle of the conic-shaped holes and the position of the cavitation.

First in the walls of the holes:

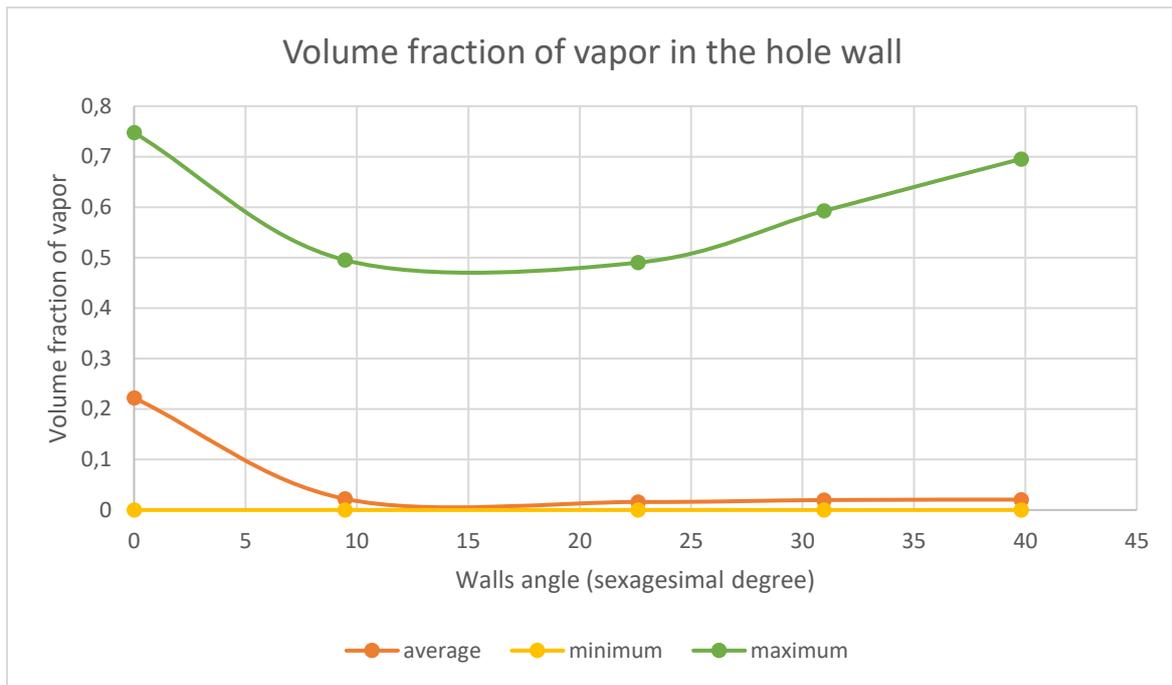


Figure 125. Variation of the volume fraction of vapor in the walls of the holes, by changing the angle of the conically shaped holes. We can see the variation of the maximum, minimum and averaged values of the variable in the surface

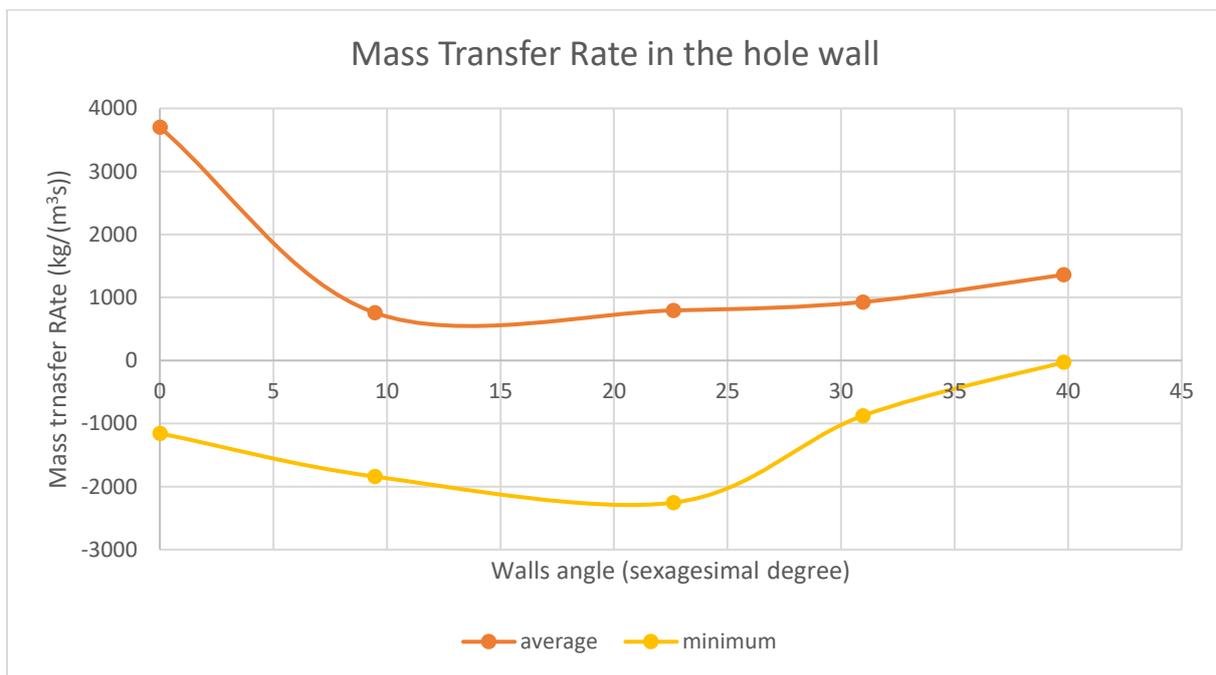


Figure 126. Variation of the mass transfer rate in the walls of the holes, by changing the angle of the conically shaped holes. We can see the variation of the maximum, minimum and averaged values of the variable in the surface

And in the walls downstream the holes:

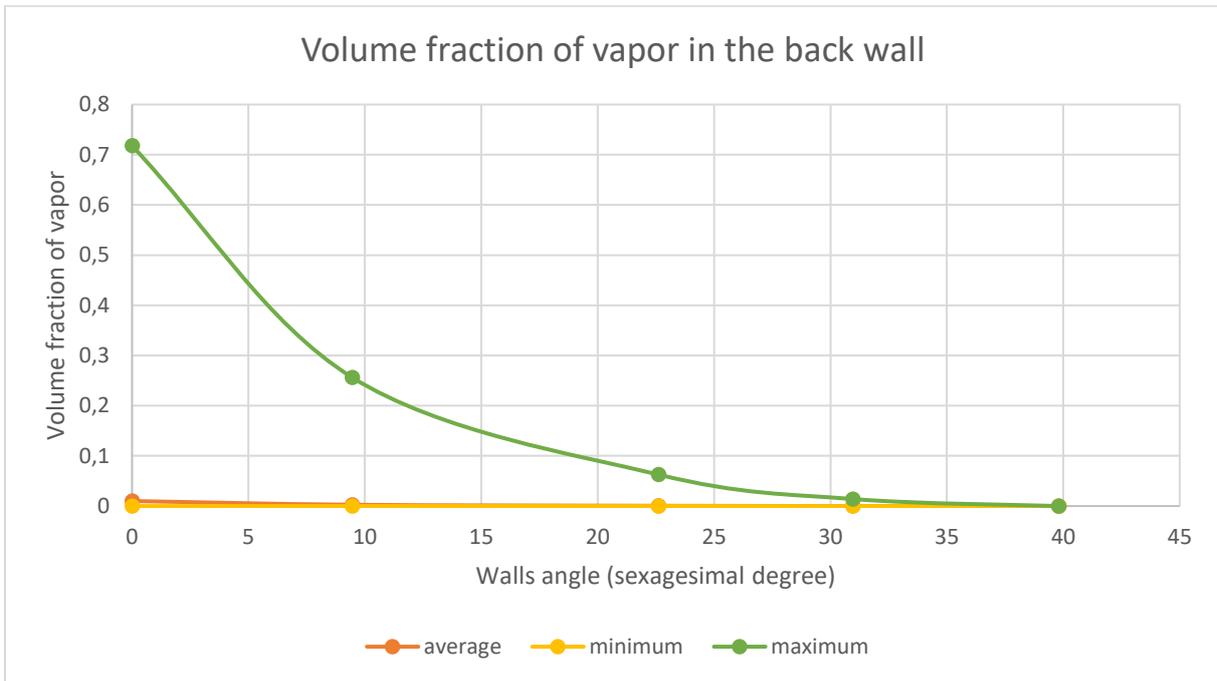


Figure 127. Variation of the volume fraction of vapor in the walls downstream the holes, by changing the angle of the conically shaped holes. We can see the variation of the maximum, minimum and averaged values of the variable in the surface

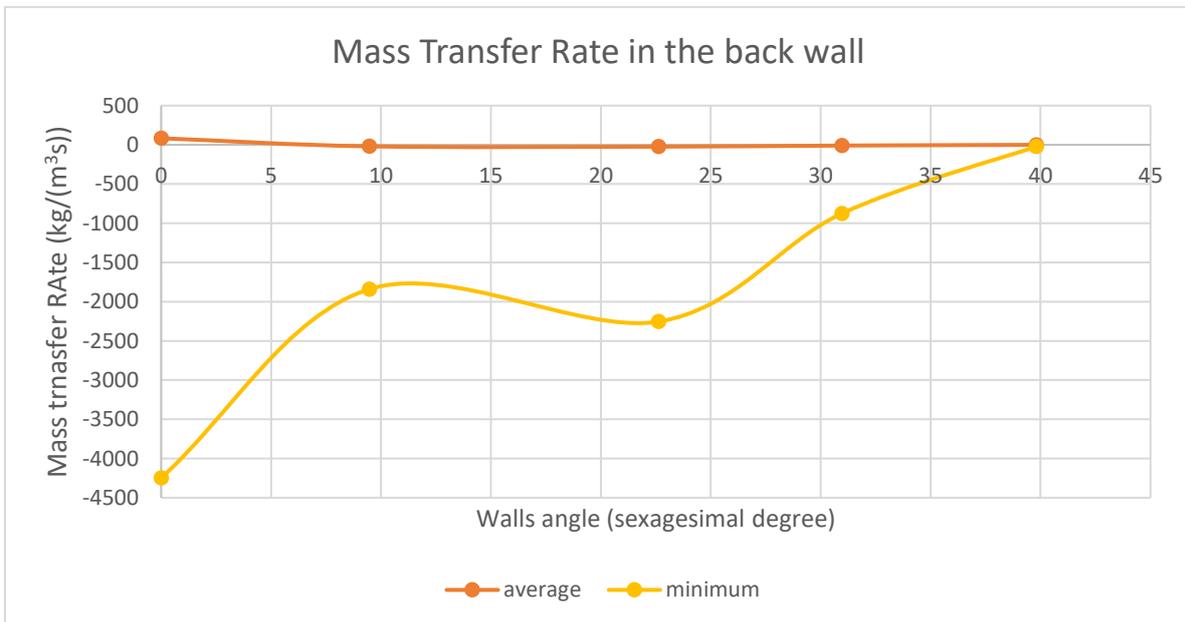


Figure 128. Variation of the mass transfer rate in the walls downstream the holes, by changing the angle of the conically shaped holes. We can see the variation of the maximum, minimum and averaged values of the variable in the surface

After looking at the results, we can see that increasing the angle the minimum mass transfer rate tends to zero on both surfaces. Although the volume fraction of vapor is increasing in the hole surfaces, this can be easily explained with the variation of the mass transfer rate. The mass transfer rate gets positive, which means that the fluid is evaporating, not cavitating. Therefore, the walls of the holes are in contact with vapor, but the cavitation is occurring far away from the surface. Contrarily, in the walls downstream the hole, the volume fraction of vapor tends to zero when the conic angle increases, as the mass transfer rate does.

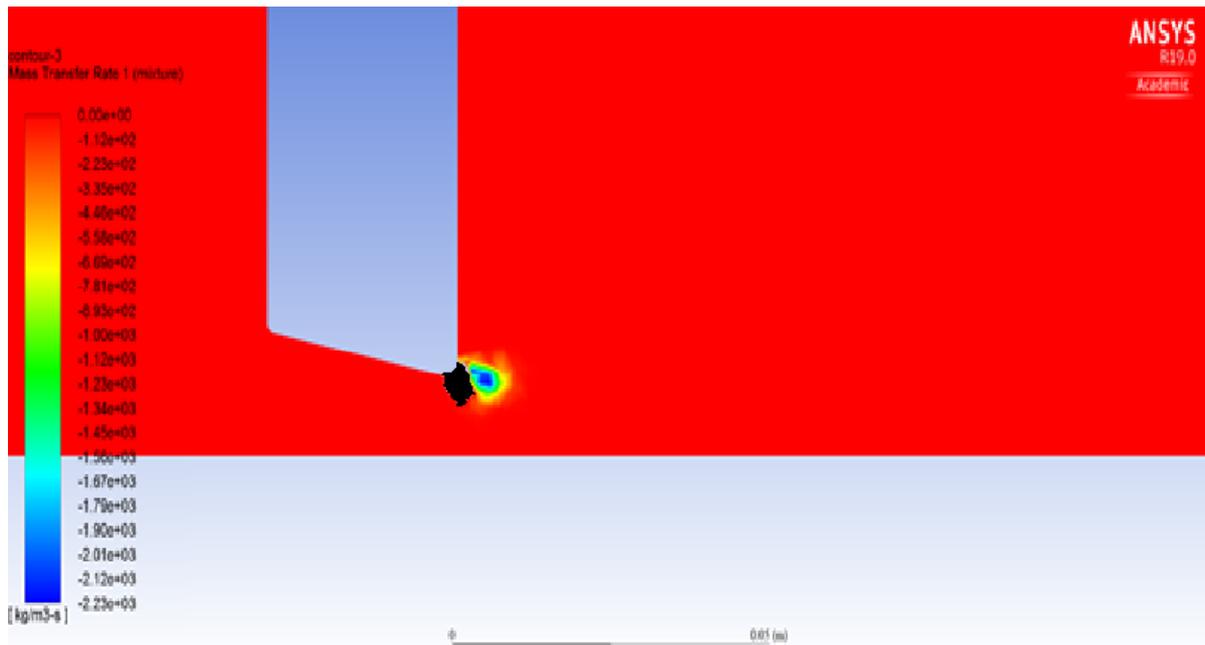


Figure 129. The plot of the mass transfer rate on the hole. Only the negative mass transfer rate has been plotted.

In Figure 129, we can see the plot of the mass transfer rate around the hole. Only the negative mass transfer rate, cavitation, has been plotted. The black zone is the region of evaporation and the region in red is complete liquid. Therefore, the region of various colors is the cavitation. It is easy to see that the cavitation it is separated from the surfaces.

5.2.1.4 Conclusion

These results are heavily linked to the change of pressure and speed through the conic shape. The change of section along the conic shape makes the end of the cone the narrowest section, and so, the section with the highest speed and lowest pressure (Figure 130 and Figure 131). The conic shape makes, as well, a component of the velocity, not only in the axis direction but also towards the center, especially close to the walls of the cone (Figure 130). Combining these characteristics, the result is the fluid with the highest volume fraction of vapor directed far away from the surfaces. And so, the cavitation will be far away too.

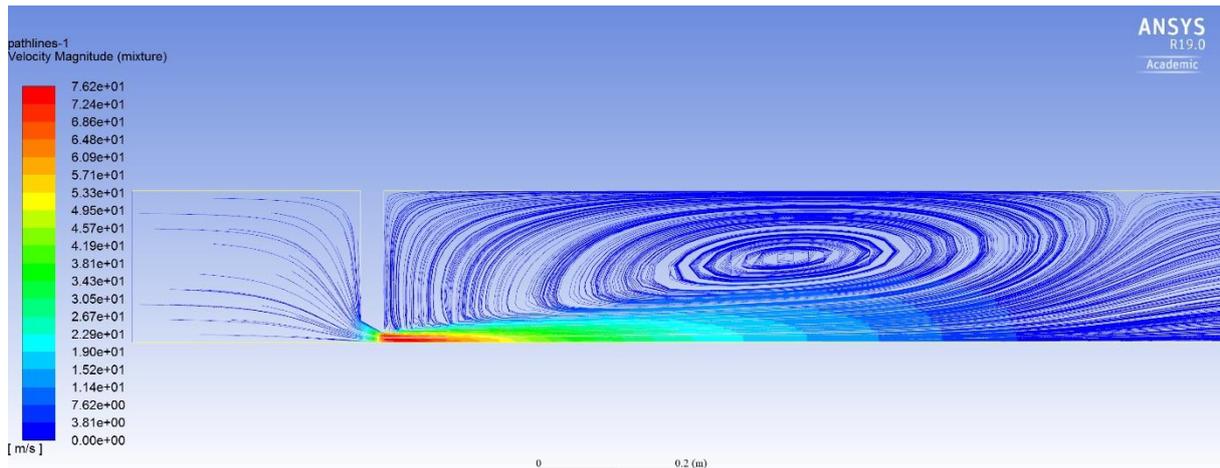


Figure 130. Streamlines of the velocity magnitude. The streamlines are the direction of the velocity and the color is the magnitude.

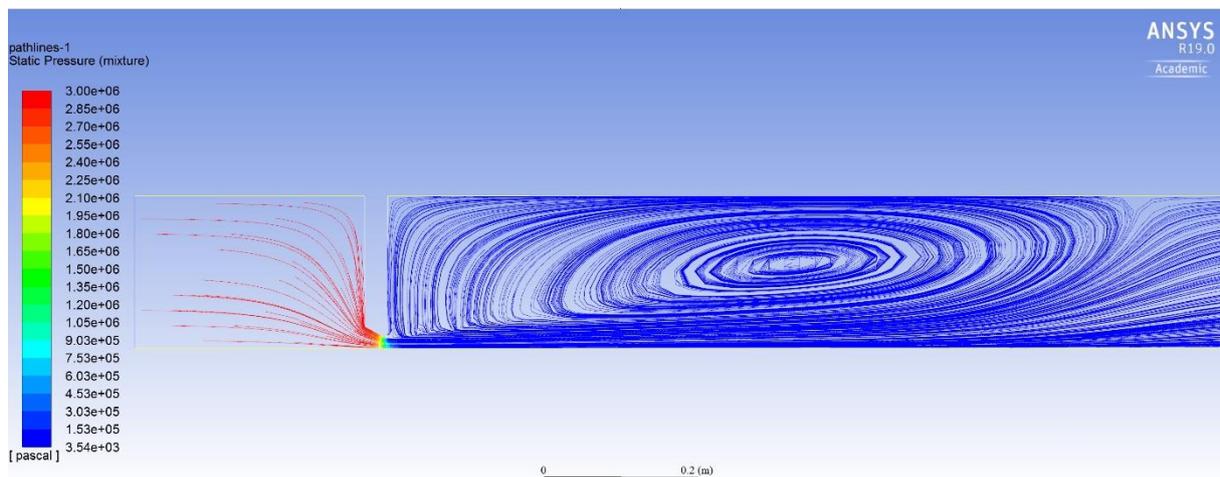


Figure 131. Streamlines of the static pressure. The streamlines are the direction of the velocity and the color is the static pressure.

Although the conic shape has some disadvantages against the cylindrical shape: the production cost is higher and the energy dissipation is lower, due to its more hydrodynamic shape. The avoidance of cavitation is one of the priorities of this project. However, this was not a final decision.

The decision was to keep the conic angle in 40° . Because the results showed that, in this angle, the cavitation almost disappears from the surfaces.

5.2.2 Strength analysis

5.2.2.1 Model

Before running the flow analysis of the complete system, the group decided to run a linear static FEM analysis with the Mechanical Module of ANSYS. The objective is to obtain the strength limits of the model before proceeding with the flow analysis. And so, avoiding simulating configurations of the valve which cannot withstand the loads.

The procedure has been to variate the input parameters of the Table 26 in several analyses. Then, the output parameter has been plotted against all of them to find any strong relationship (data on Annex 1).

Input parameters	Output parameters
Inner cylinder length	Safety factor
Inner cylinder radius	
Number row of holes	
Number of holes per row	
Holes radius	
Thickness of the valve body	
Pressure applied	

Table 26. Input and output parameters of the FEM analysis carried out on the valve

As this is just a rough analysis and the material selection has not been done yet, the safety factor is calculated for a common construction steel with a yield stress limit of 250 MPa.

$$SF = \frac{\text{Maximum Von Mises Stress}}{250 \text{ MPa}} \quad (2)$$

5.2.2.2 Results

After running several FEM analyses varying the input parameters, the results were plotted to find any correlation between the input and output parameters. For all the graphs go to Annex 1.

For the processing of the results the group used Excel. We interpolated the results to find a linear correlation, and used the statistical variable R^2 , provided by Excel, to define the correlation. This value measures how good is the adjustment to a linear interpolation, with 0 meaning no correlation and 1 total correlation.

Input parameters	R^2
Inner cylinder length	0.0075
Inner cylinder radius	0.043
Number row of holes	0.0002
Number of holes per row	0.0087
Holes radius	0.0095
Thickness of the valve body	0.6333

Table 27. Linear correlation between the input parameters of the geometrical model of the valve and the safety factor

5.2.2.3 Conclusion

After analyzing the linear correlation and the plots, it is easy to see that the only parameter with real influence on the safety factor is the thickness of the valve body. Although there is no an exact value of the thickness, the group kept the value obtained from the *Technical document: Material* and prepare the model to change it after the material and the FEM analysis ends

5.2.3 Valve model

After choosing a shape for the holes, it was integrated into the complete valve model. The model was created depending on the undefined parameters. By modifying these parameters, the rest of the requirements must be fulfilled.

5.2.3.1 Model

The model includes the whole valve, simplified by the circular symmetry.

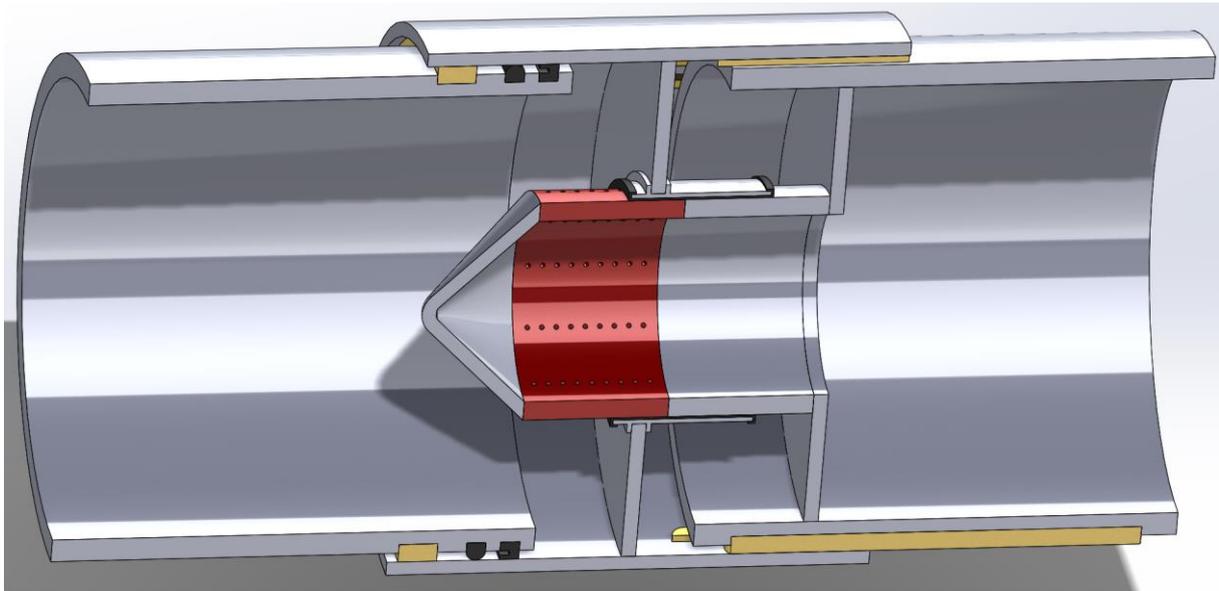


Figure 132. CAD model after the second increment of the design history used in this increment to optimize the volume flow rate

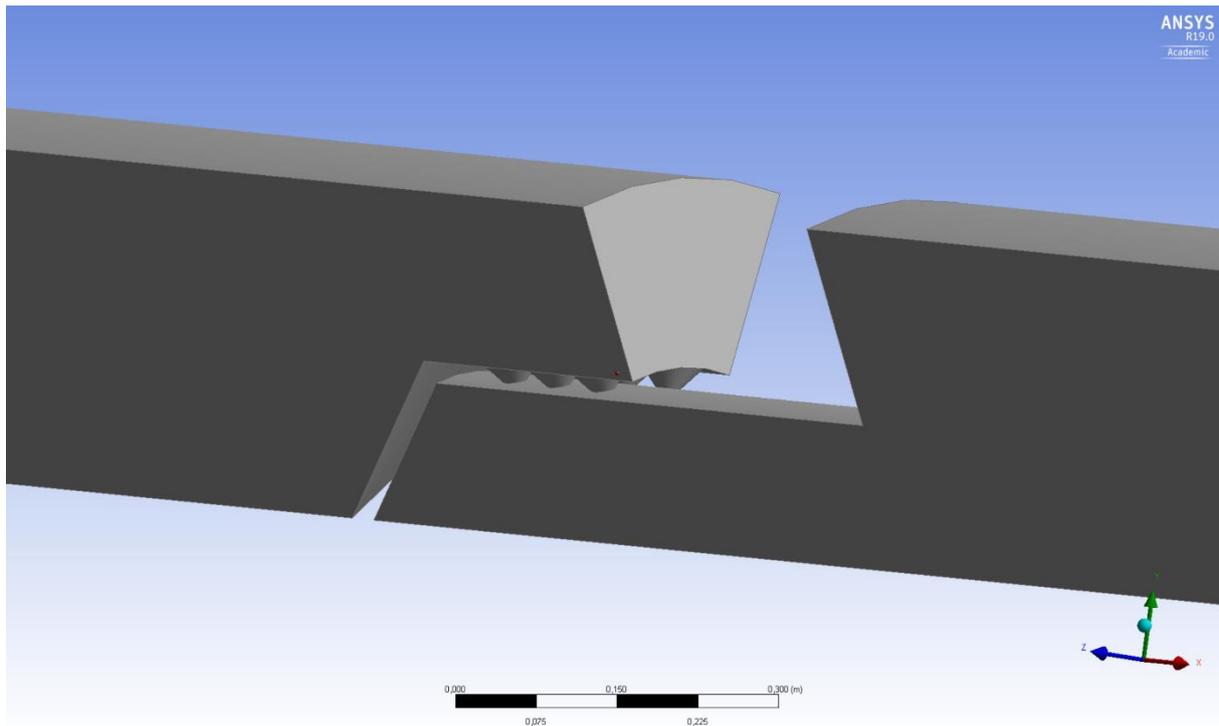


Figure 133. CAD model in the Design Module in ANSYS of the valve model from the second increment

The objective was finding the values of the rest of the parameters, which made the volume flow rate $3 \text{ m}^3/\text{s}$, from the requirement RQ-2, while the necessary material is minimized.

Input parameters	Output parameters
Inner cylinder length	Volume flow rate
Inner cylinder radius	
Number row of holes	
Number of holes per row	
Holes radius	

Table 28. Input and output parameters of the complete model of the valve in the second increment

For having faster and more stable simulations, this models did not include the cavitation effects. However, the minimum absolute pressure was limited to the vapor pressure for avoiding an unlimited drop of pressure.

5.2.3.2 Optimization process

The input of this simulation is a group of parameters, which all of them have influence on the output parameter. This can be faced by varying all the parameters until finding the right value of the volume flow rate. However, this path is inefficient, especially for a simulation as time consuming as this is. Therefore, the group decided to prepare a path to follow during the optimization:

- 1) Some of the parameters can be related mathematically due to the geometrical relations of the model.
 - a. The number of holes per row can be defined by the radius of these holes and the length of the inner cylinder, leaving a certain space between the holes.
 - b. The radius of the inner cylinder and the radius of the holes can define the number of rows, again, leaving some space between holes.

Independent input parameters	Output parameters
Inner cylinder length	Volume flow rate
Inner cylinder radius	
Holes radius	

Table 29. New input independent and output parameters of the complete model of the valve in the second increment, after the mathematical relation of the parameters

- 2) A range of values was assigned to each input parameter, and then, some simulations were run to find the relation between these parameters and the volume flow rate.

Independent input parameters	Range of values
Inner cylinder length	0,5 - 0,7 m
Inner cylinder radius	0,13 – 0,17 m
Holes radius	20 – 30 mm

Table 30. Range assigned to the input parameters to variate them during the simulations

- 3) When having these relationships, the values are interpolated to find the right configuration of the input parameters. And then, update the data to increase the accuracy of the interpolation.

5.2.3.3 Simulation process

Due to the size of the model and the limitations of the academic license, the mesh should be optimized to acquire good results without reaching the mesh size limit. Therefore. The group applied the dynamic mesh optimization explained in the setup for refining the mesh only where the velocity gradient is high, and so, the mesh is refined only where it is necessary and not in a complete region.

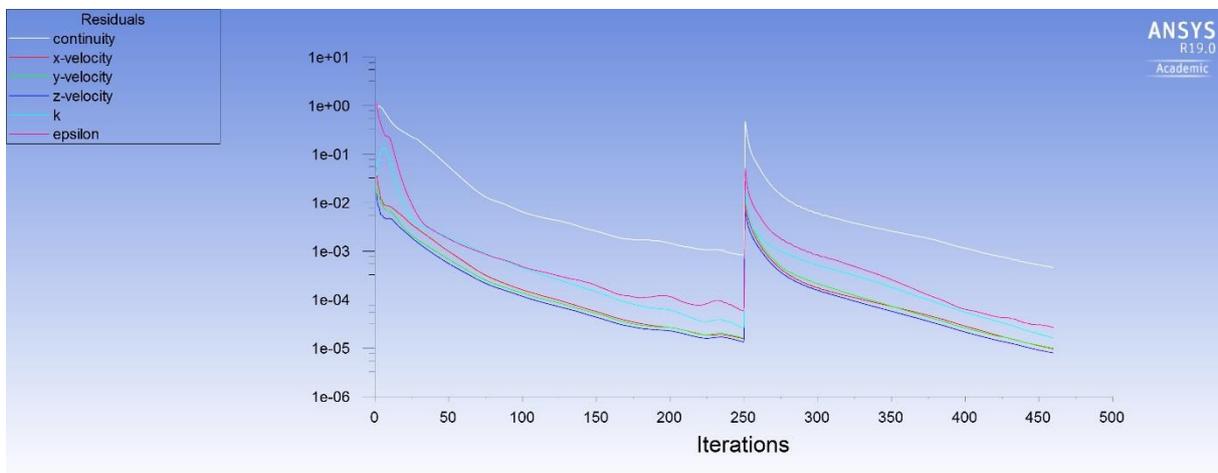


Figure 134. Graph of the residuals showing the refinement point in the discontinuity

In the Figure 134, we can see the residuals graph. In the iteration 250 the mesh was refined. That is why the residuals got high again.

5.2.3.4 Results

After plotting the results of the first step of the optimization path, the group used, again, the R^2 parameter for measuring the correlation. For the complete data go to Annex 2.

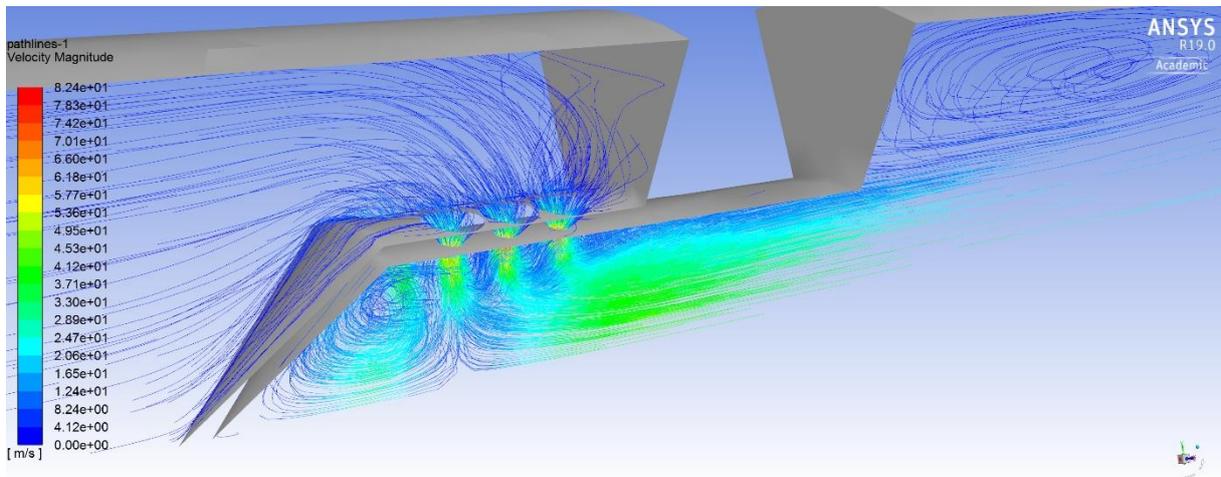


Figure 135. Streamlines through the valve with a color range which represents the velocity magnitude

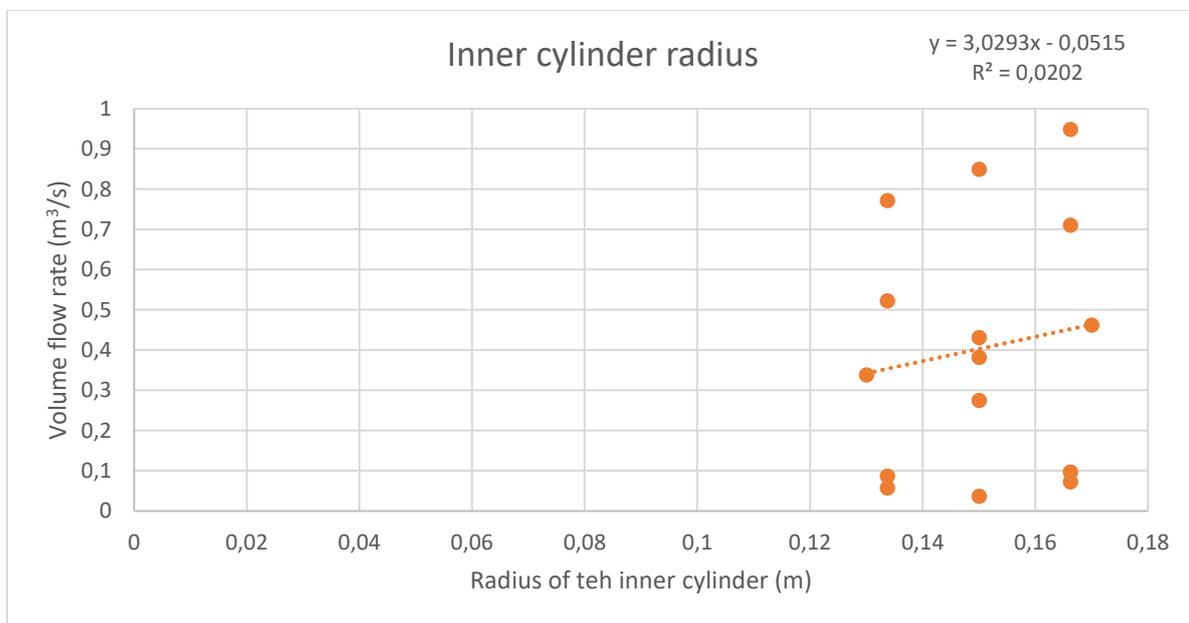


Figure 136. Relationship between the radius of the inner cylinder and the volume flow rate

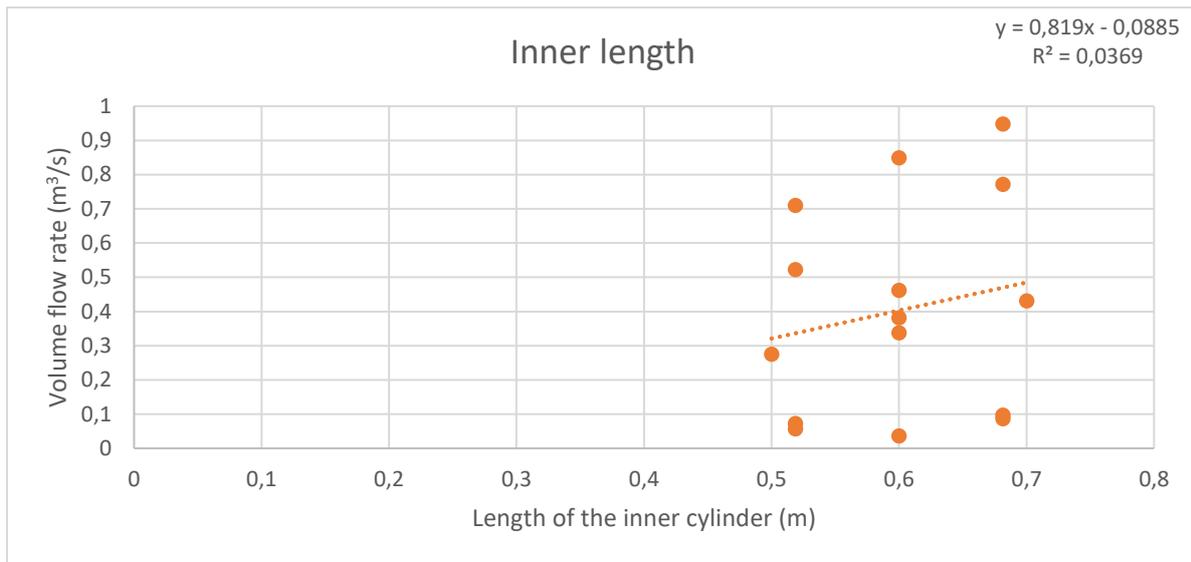


Figure 137. Relationship between the length of the inner cylinder and the volume flow rate

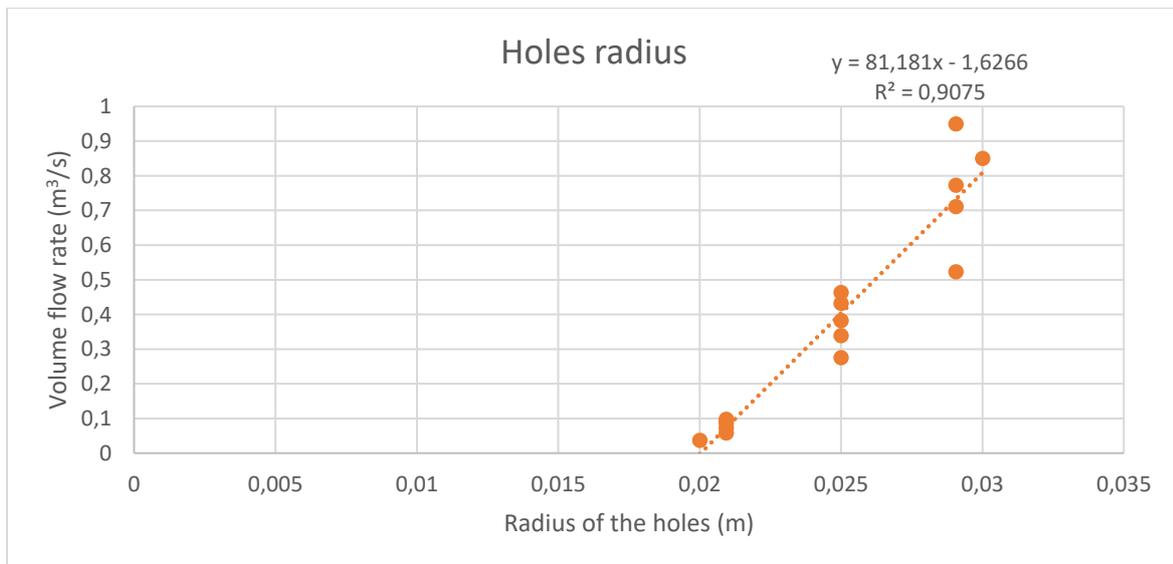


Figure 138. Relationship between the radius of the holes and the volume flow rate

Independent input parameters	R ²
Inner cylinder length	0.0202
Inner cylinder radius	0.0369
Holes radius	0.9075

Table 31. Correlation between the input parameters and the volume flow rate through the statistical variable R²

It is easy to see that the strongest relationship is with the hole radius. This is easily explainable. If the radius increases, the area where the fluid can go through increases as well. Therefore, the group interpolates using the equation given by excel to get the right volume flow rate:

$$Q = 81,181r - 1,6266; Q = 3 \text{ m}^3/\text{s} \rightarrow r = 57\text{mm} \quad (3)$$

For the rest of the dimensions the influence is neglectable. Therefore, we left the definitions of these dimension for the other areas of the design and took, initially, the medium value of the previous range. And then, repeat the simulation with the new values. The volume flow rate was 4,66 m³/s. So, we updated the data:

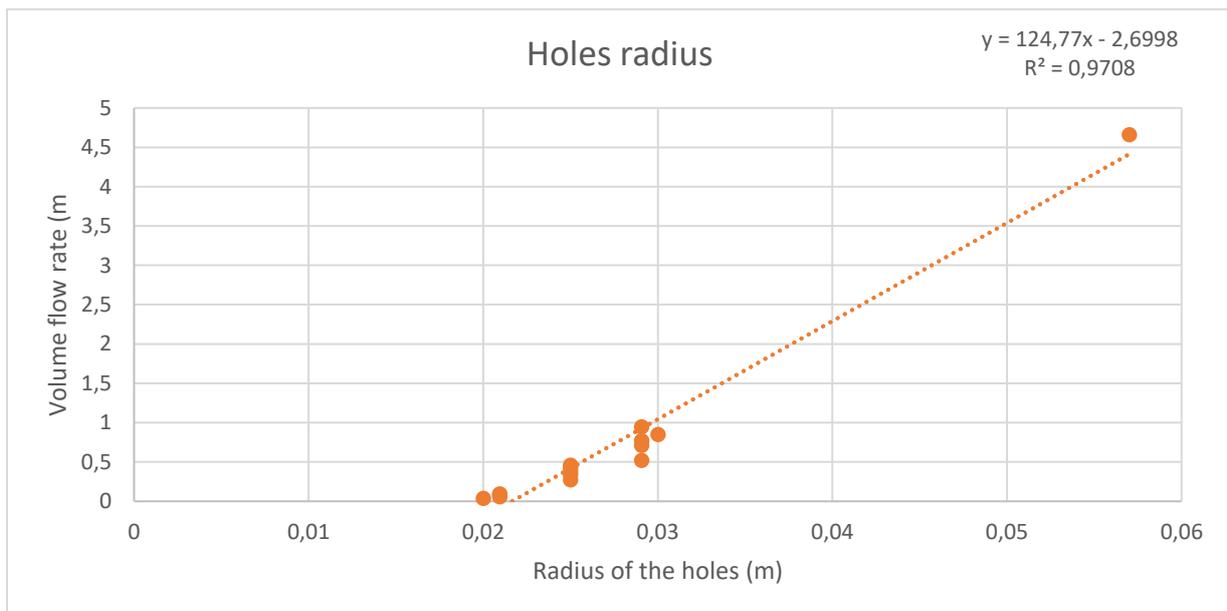


Figure 139. Relationship between the radius of the holes and the volume flow rate

By interpolating the new data:

$$Q = 124,77r - 2,6998; Q = 3 \text{ m}^3/\text{s} \rightarrow r = 47\text{mm} \quad (4)$$

The group ran the simulation with the new values. The volume flow rate obtained was 3,561 m³/s.

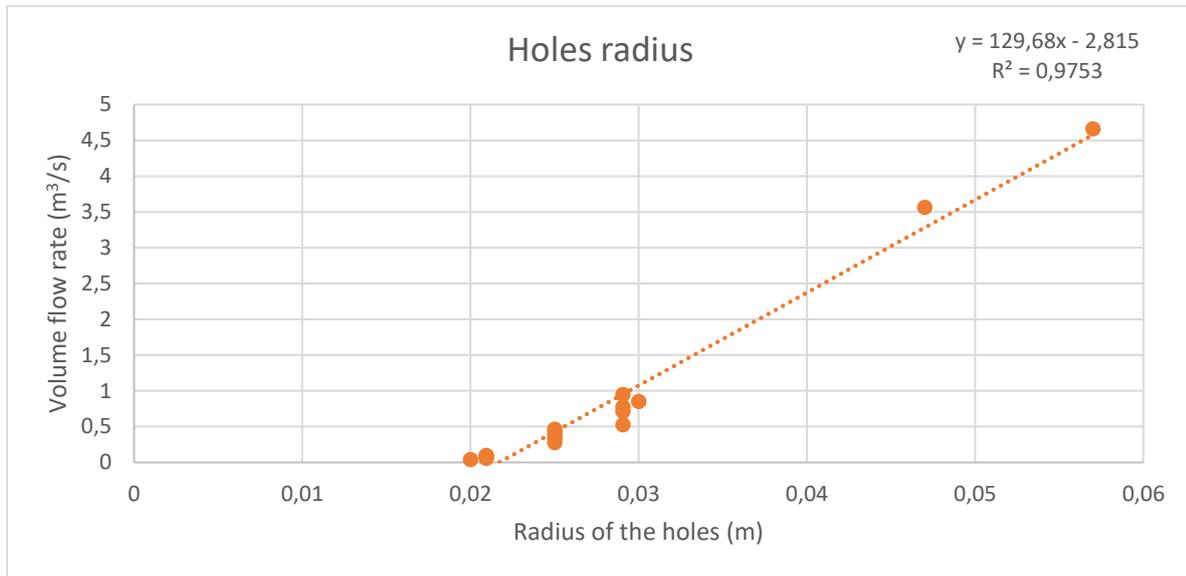


Figure 140. Relationship between the radius of the holes and the volume flow rate

New interpolation:

$$Q = 129,68r - 2,815; Q = 3 \text{ m}^3/\text{s} \rightarrow r = 45\text{mm} \quad (5)$$

And repeat the simulation, where we got 3,316 m³/s:

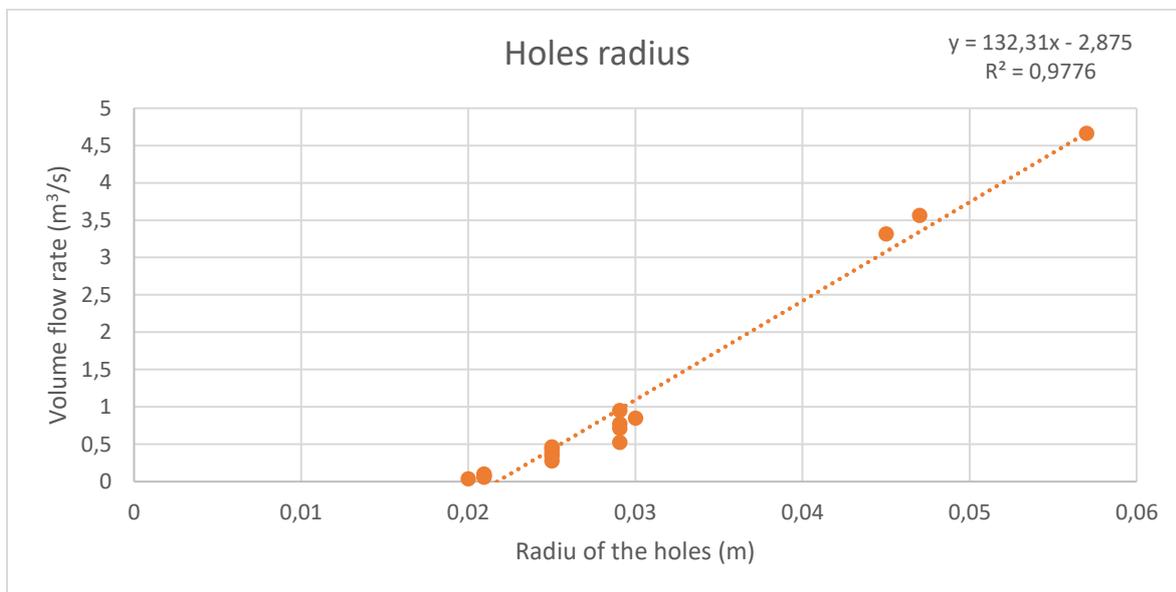


Figure 141. Relationship between the radius of the holes and the volume flow rate

The group saw that the linear interpolation with all the values was losing accuracy, so we decided to use the new values only:

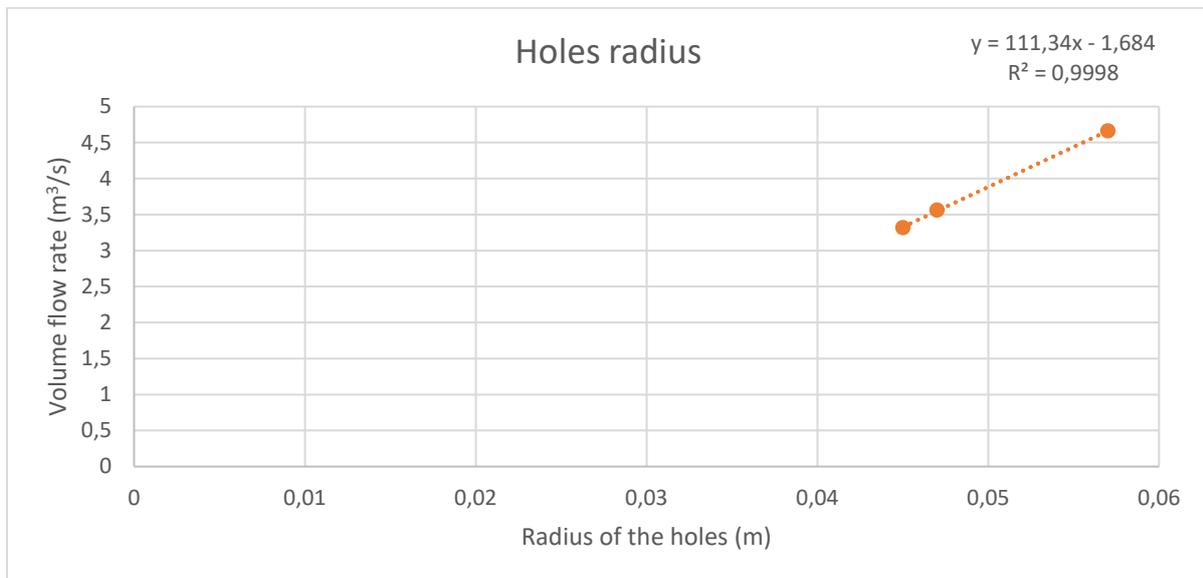


Figure 142. Relationship between the radius of the holes and the volume flow rate

And we interpolated again:

$$Q = 111,34r - 1,648; Q = 3 \text{ m}^3/\text{s} \rightarrow r = 42 \text{ mm} \quad (6)$$

The group simulated with 42mm and got 3,065 m³/s. We consider this adjusted to the requirements.

5.2.3.5 Conclusion

The group found the dimensions which fulfilled the requirements. These values were sent to the other areas of the design to continue with the iterative approach.

5.3 Third increment

After the second increment of the design configuration, explained in the document "Design Document", some changes were done to the model. The configuration had to be optimized to find the right volume flow rate for this configuration.

5.3.1 Model

The model come from the forth increment of the design. It has the connection of the inner part and the main pipe further from the holes.

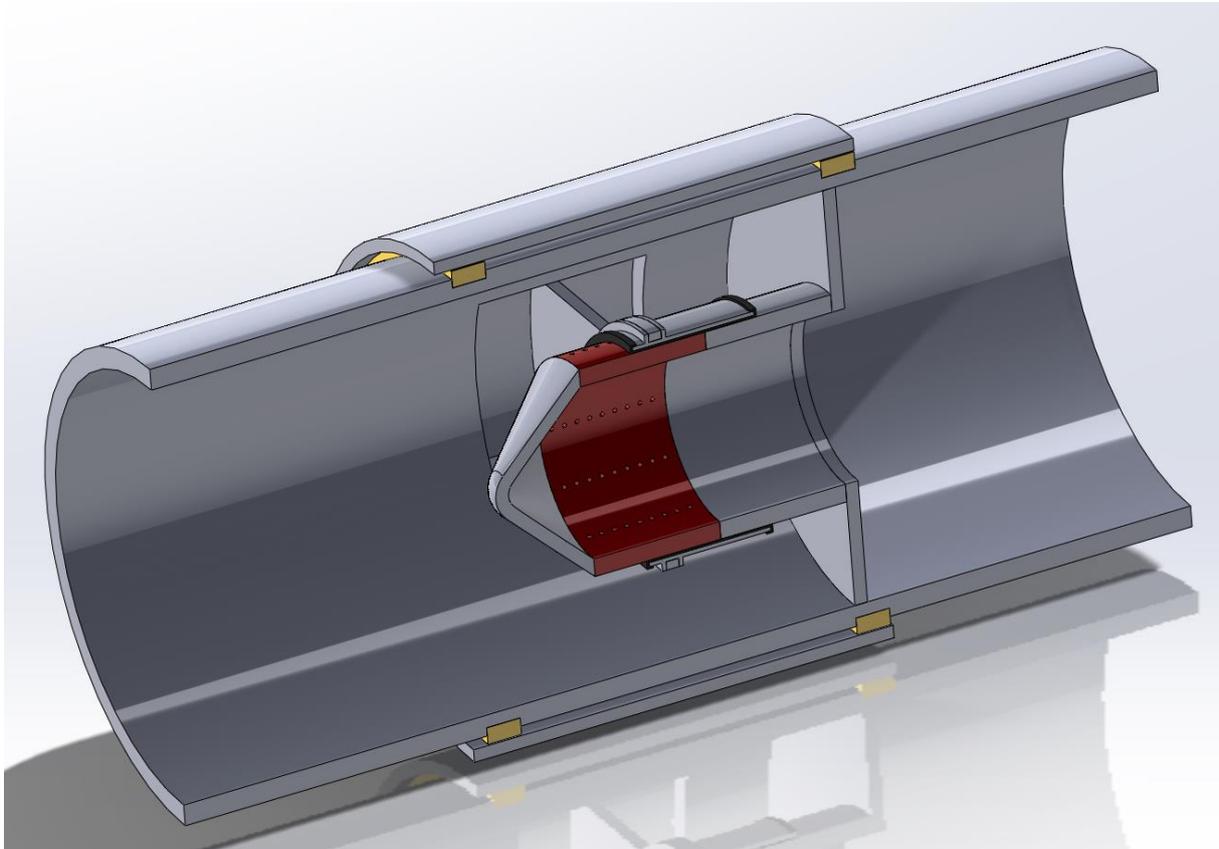


Figure 143. CAD model of SolidWorks resulting from the forth increment of the design history

The model was designed in the Design Module of ANSYS. The group neglected the small geometrical shapes, which did not affect the flow performance, for simplifying the analysis.

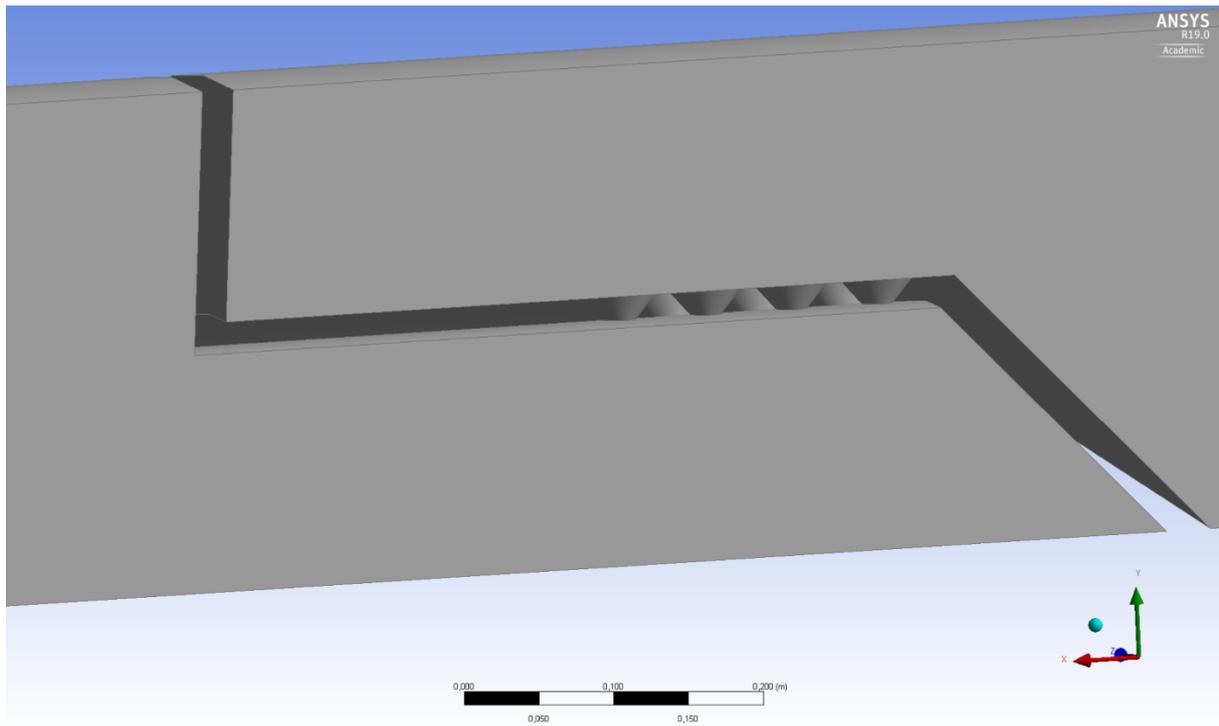


Figure 144. CAD model of the valve for the third increment flow analysis simulations

5.3.2 Simulation process

As the model was similar, the simulation performed was the same as in the second increment. And it developed the same as before.

5.3.3 Results

Due to the higher diameter of the inner cylinder, more holes fitted into it. Therefore, the flow rate was higher. The group decided to reduce the number of holes by removing one circular row of holes.

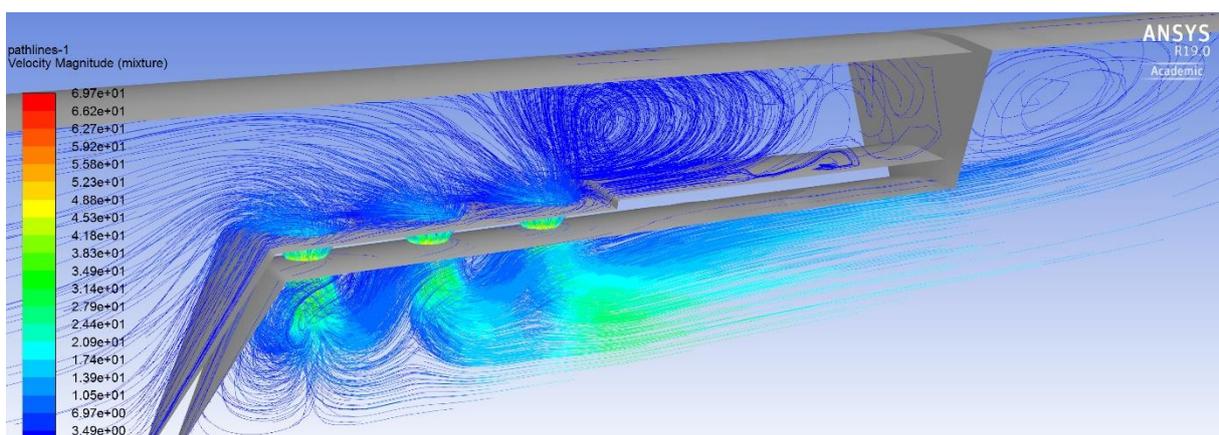


Figure 145. Velocity magnitude plot. The streamlines are the direction of the fluid and the color is represents the magnitude of the velocity

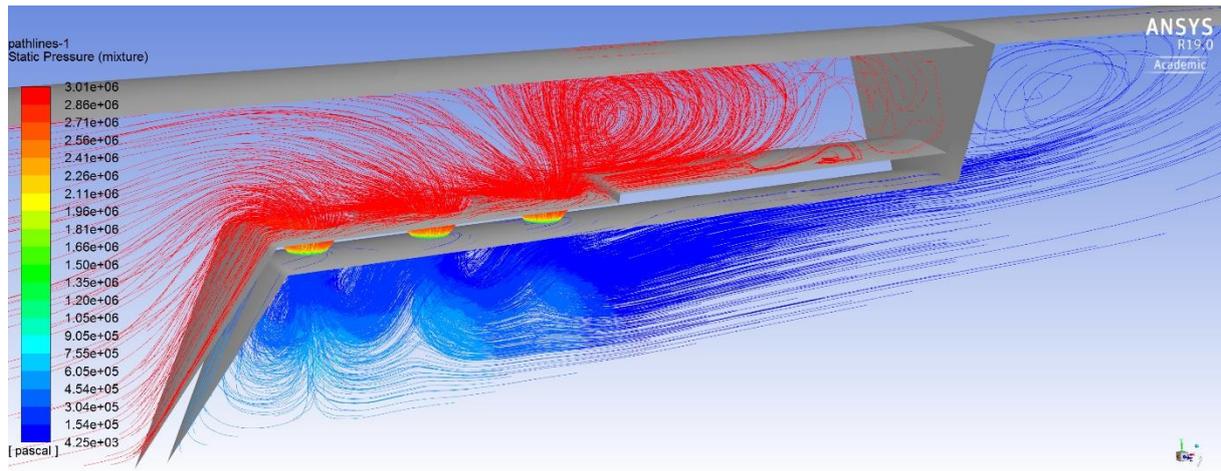


Figure 146. Static pressure plot. The streamlines are the direction of the fluid and the color is represents the magnitude of the static pressure

5.3.4 Conclusion

The result of removing a hole was expected to increase strength and save material. The results were sent back to the other areas of the design.

5.4 Fourth increment

After running a FEM analysis and the sixth increment of the design, some changes were done on the model. Therefore, the volume flow rate should be calculated again.

5.4.1 Model

The main change of the model is the change of the linear pattern to an alternate pattern. This pattern provides more strength to the model.

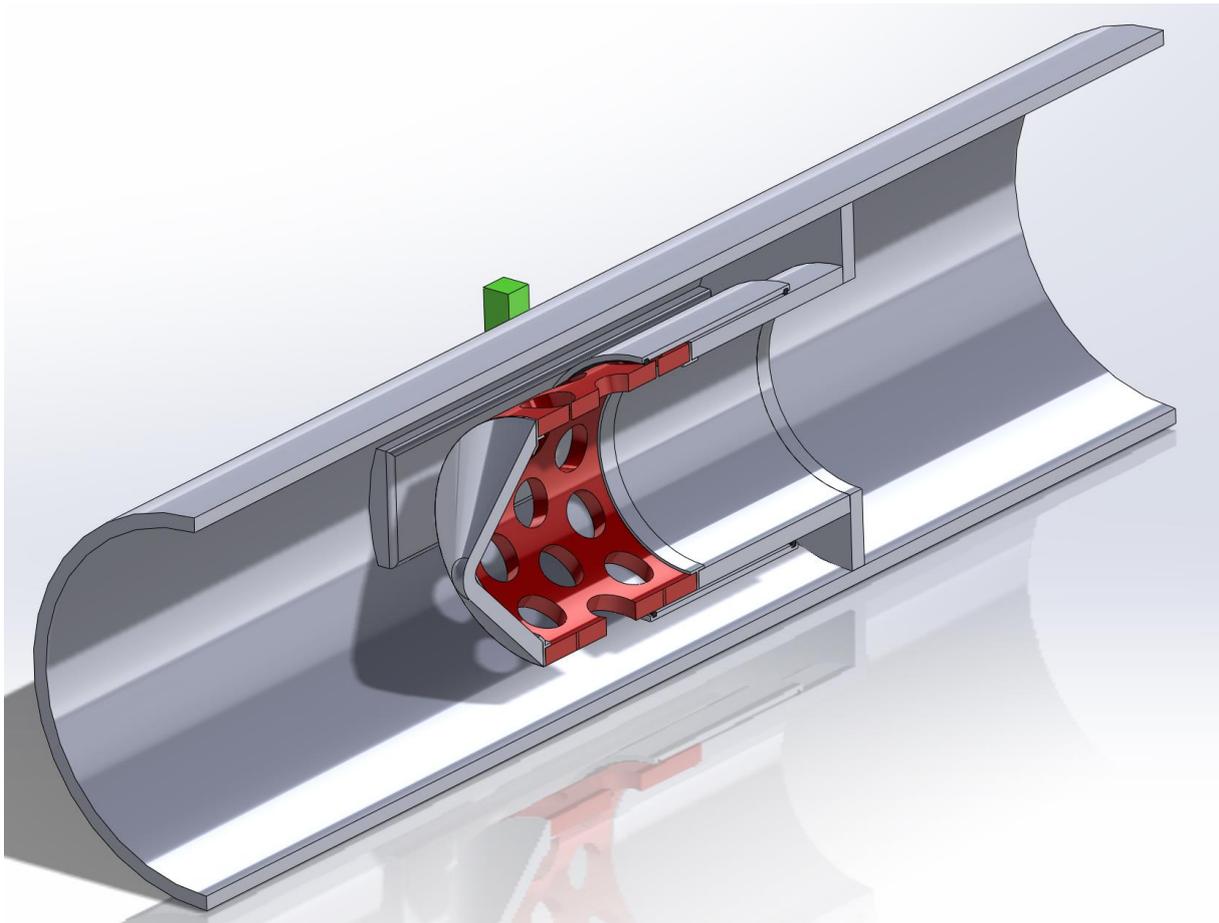


Figure 147. Resulting model from the sixth increment of the design

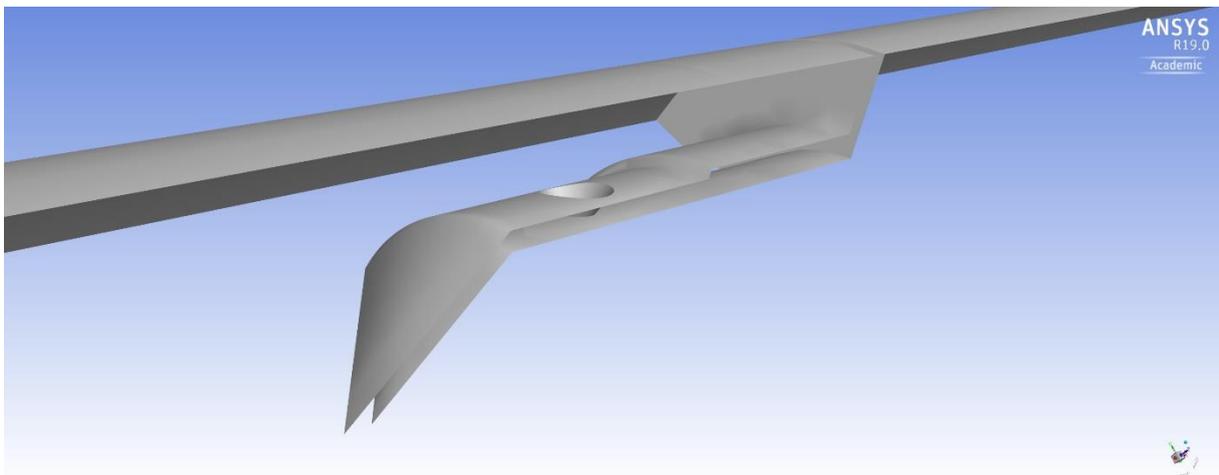


Figure 148. Model made in ANSYS for the flow analysis. Only the solid walls are shown in this picture.

5.4.2 Simulation process

As the model was similar, the simulation performed was the same as in the second increment. And it developed the same as before.

5.4.3 Results

The volume flow rate fulfilled the requirement due to the minimal changes done.

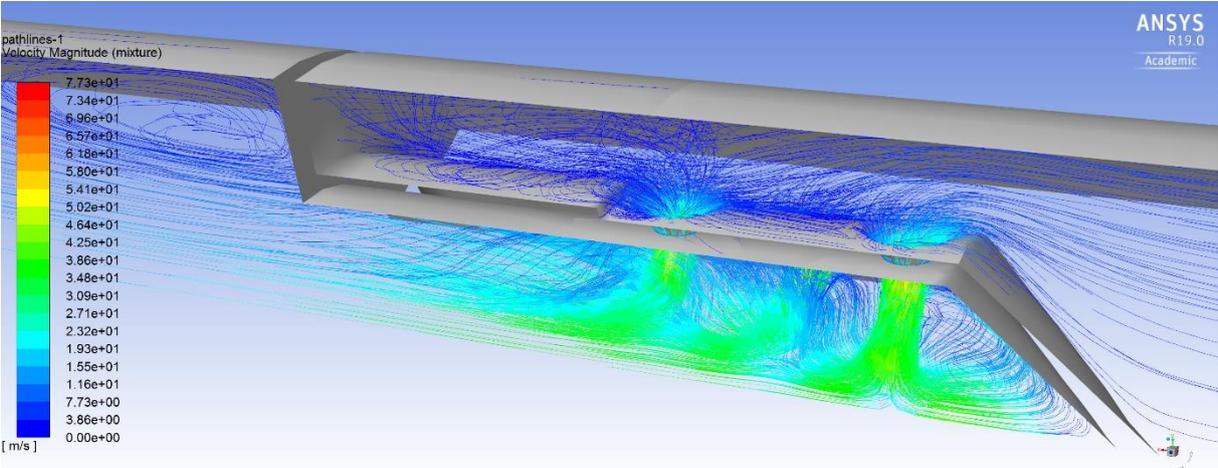


Figure 149. Velocity magnitude plot. The streamlines are the direction of the fluid and the color is represents the magnitude of the velocity

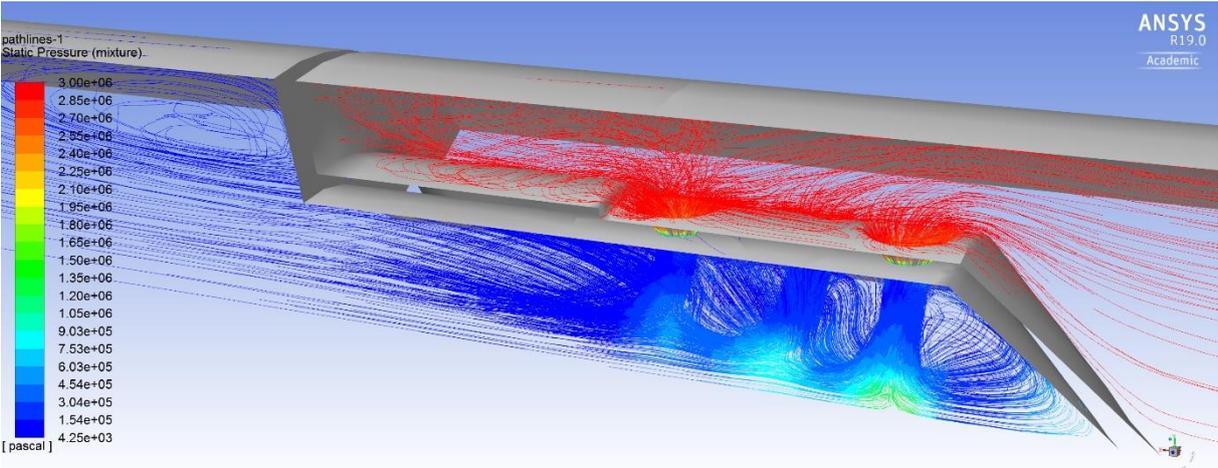


Figure 150. Static pressure plot. The streamlines are the direction of the fluid and the color is represents the magnitude of the static pressure

5.4.4 Conclusion

Changes in the pattern of the holes did not result in changes in the volume flow.

6 Flow characteristic

As expressed in the requirements, the flow characteristic must be predictable (RQ-3). Moreover, there are different types of predictable flow characteristic. The objective is to get an equal percentage characteristic, but linear flow characteristic is also accepted in the industry as a good result (see Appendix J).

For acquiring the flow characteristic, the group ran several simulations varying the opening grade. We queued 20 simulation varying a 5% the opening grade. Then, the volume flow rate data was processed with excel to obtain the flow characteristic curve.

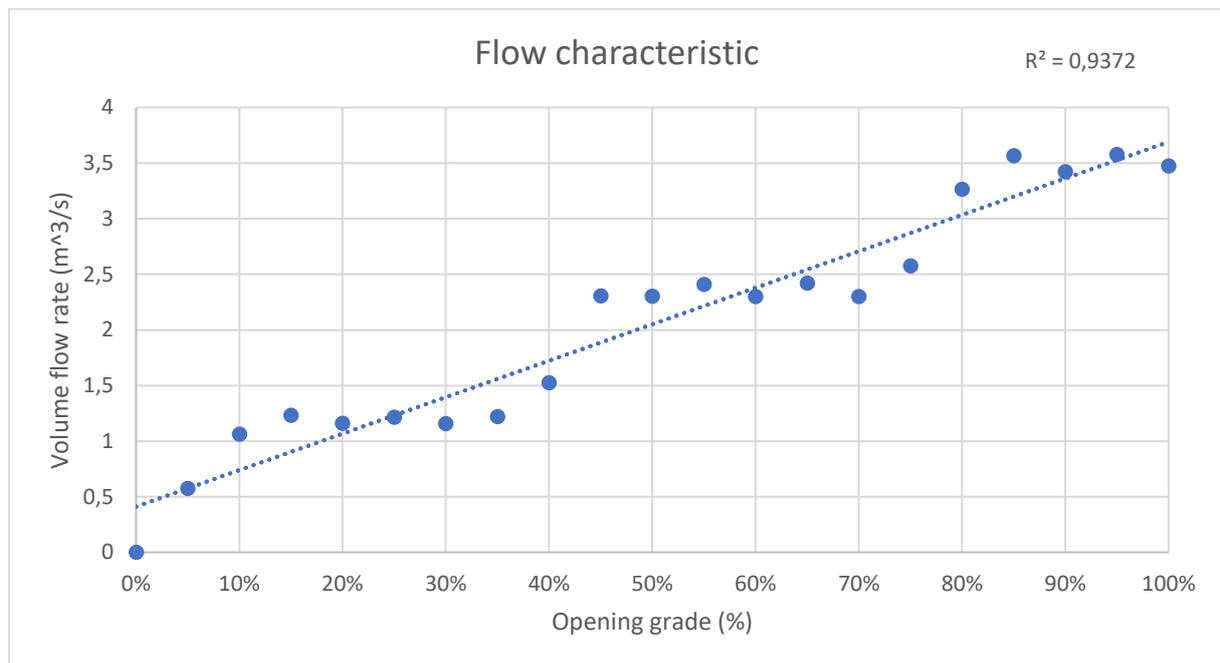


Figure 151. Plot of the points relating the volume flow rate and the opening grade of the valve obtained after all the simulations.

The result is a flow characteristic almost linear. The three wave-like variations in the curve correspond to the three holes per row in the valve. The group consider this a good result as it is a predictable and linear flow characteristic. Therefore, the requirement RQ-3 is fulfilled.

7 Result

The final design fulfils all the requirements and the results has been verified as explained in the section Validation of the results. However, as any numerical analysis, an experimental verification is needed. Due to the size and cost of the product the group is not able to construct a prototype and test it properly.

8 Annex 1

The results of the FEM analysis are plotted here. Each graph contains all the points of the simulations. In the horizontal axis it is the geometrical variable, the safety factor is in the vertical one. The R^2 and the equation of the linear interpolation is presented in each graph.

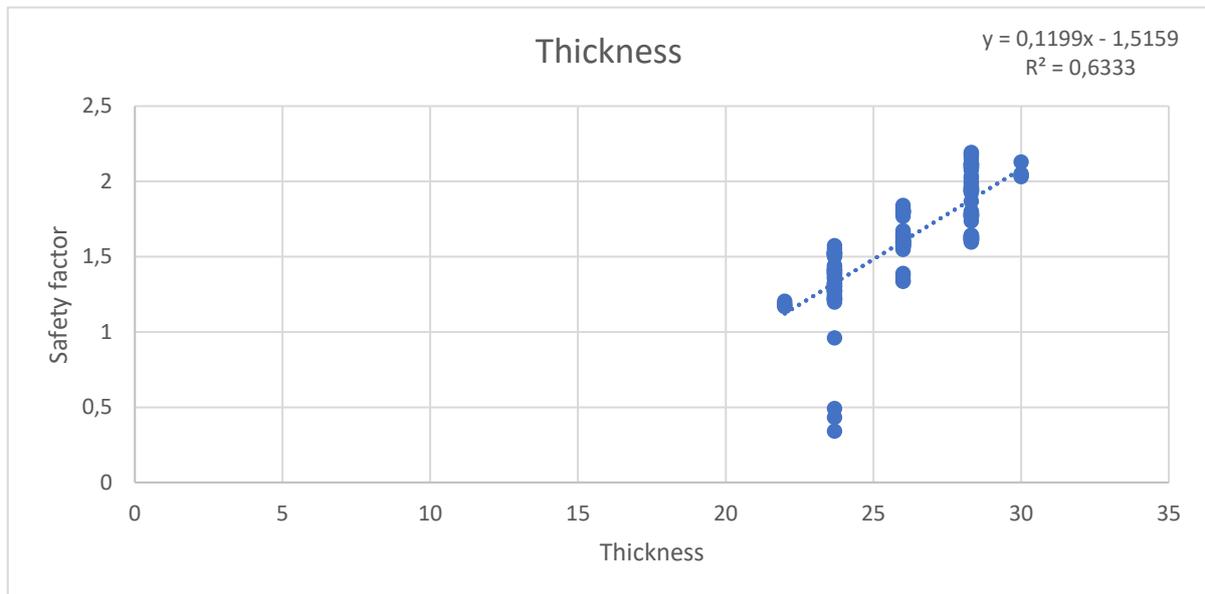


Figure 152. Relation between the thickness of the valve body and the safety factor after the FEM analysis

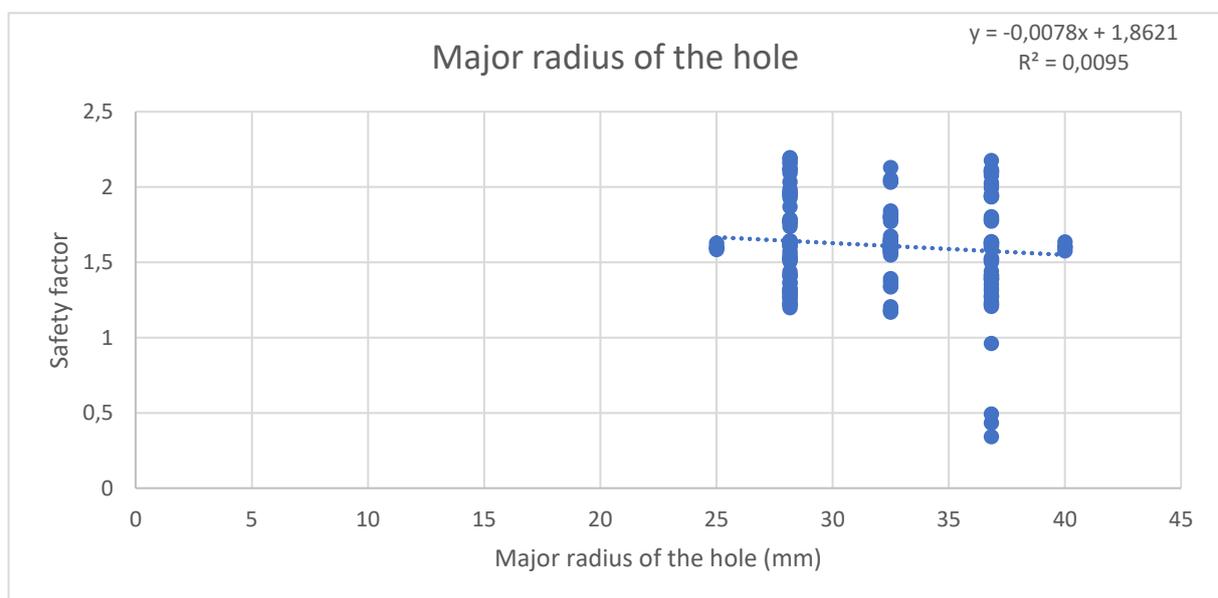


Figure 153. Relation between the bigger radius of the holes and the safety factor after the FEM analysis

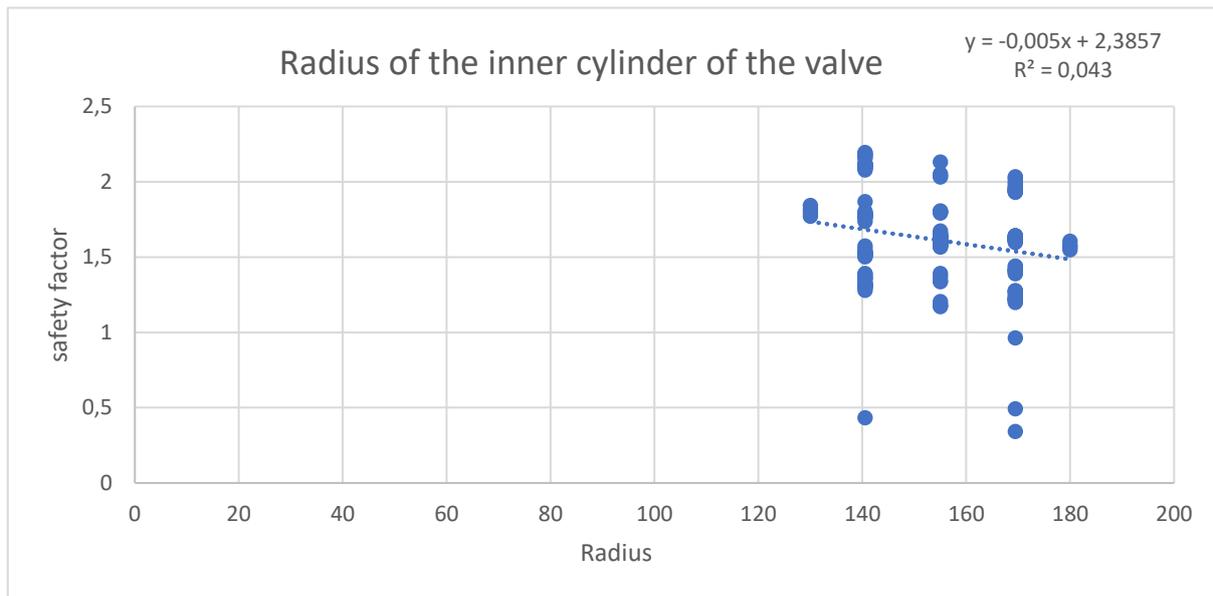


Figure 154. Relation between the radius of the inner cylinder of the valve and the safety factor after the FEM analysis

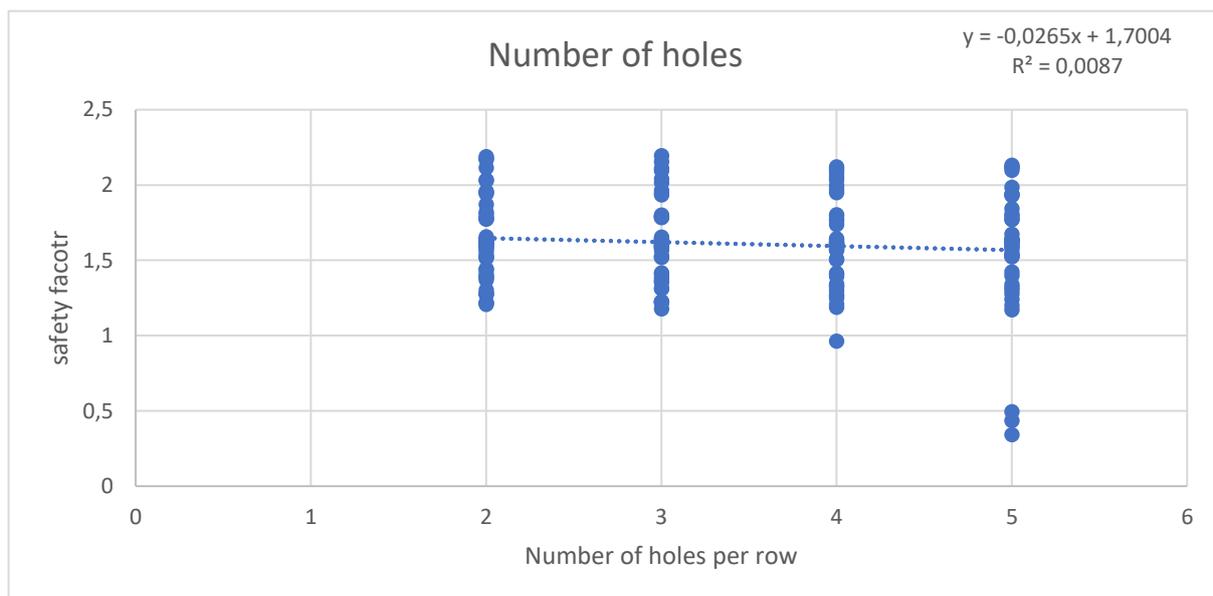


Figure 155. Relation between the number of holes per row and the safety factor after the FEM analysis

Instead of the number of rows, the group used as an equivalent parameter the angle of the circular sector in which we set one row of holes, which is proportional to the number of rows.

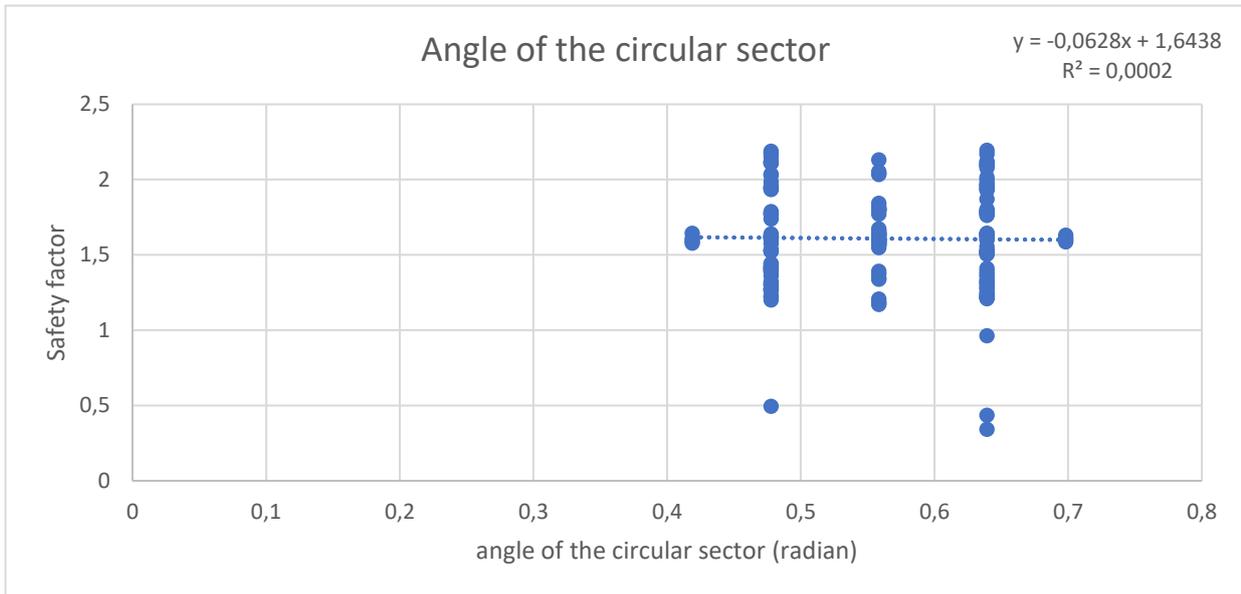


Figure 156. Relation between the angle of a circular sector with one row of holes and the safety factor after the FEM analysis

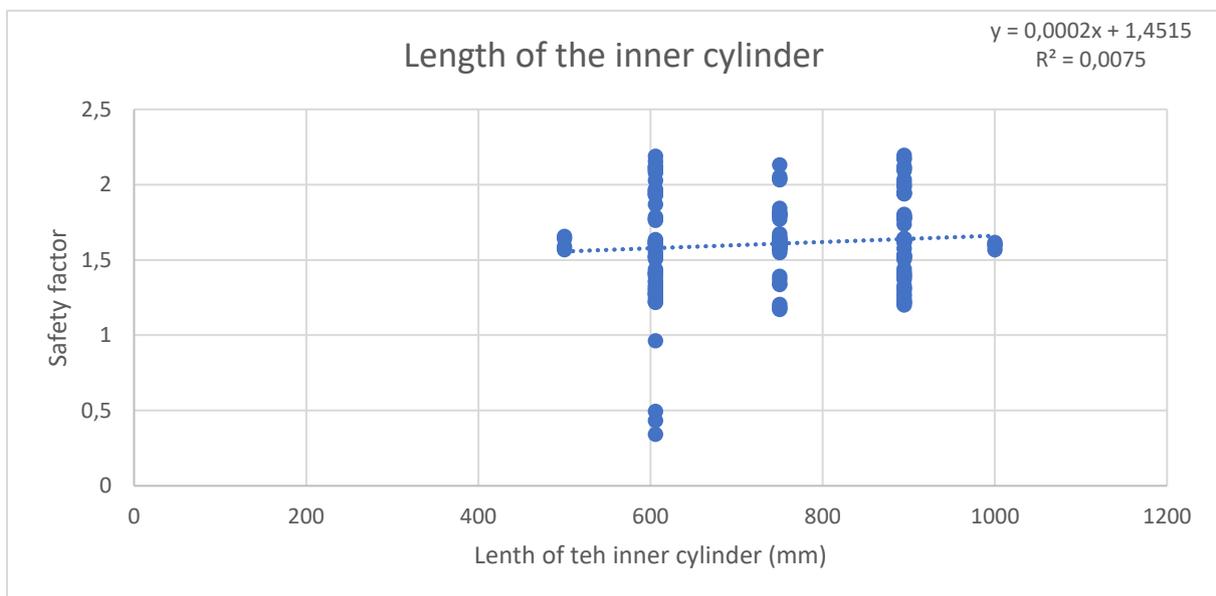


Figure 157. Relation between the length of the inner cylinder of the valve and the safety factor after the FEM analysis

9 Annex 2

Inner length (m)	Inner radius (m)	Holes radius (m)	Number of holes	Number of rows	Volume flow rate (m ³ /s)	mass imbalance	Area total (m ²)	Area/Hole (m ²)
0.500	0.150	0.025	4	18	0.275	3.5E-05	2.0E-03	2.0E-03
0.519	0.134	0.021	5	21	0.057	5.0E-05	1.4E-01	1.4E-03
0.519	0.134	0.029	4	15	0.523	2.9E-07	1.6E-01	2.7E-03
0.519	0.166	0.021	5	27	0.073	-2.2E-04	1.9E-01	1.4E-03
0.519	0.166	0.029	4	20	0.711	2.1E-05	2.1E-01	2.7E-03
0.600	0.130	0.025	5	18	0.338	-2.0E-05	1.8E-01	2.0E-03
0.600	0.150	0.020	7	27	0.037	-3.7E-05	2.4E-01	1.3E-03
0.600	0.150	0.025	5	20	0.382	6.9E-05	2.0E-01	2.0E-03
0.600	0.150	0.030	4	18	0.849	-4.4E-06	2.0E-01	2.8E-03
0.600	0.170	0.025	5	24	0.462	1.7E-05	2.4E-01	2.0E-03
0.681	0.134	0.021	7	23	0.087	7.3E-05	2.2E-01	1.4E-03
0.681	0.134	0.029	5	17	0.772	3.1E-07	2.3E-01	2.7E-03
0.681	0.166	0.021	7	27	0.097	-2.1E-05	2.6E-01	1.4E-03
0.681	0.166	0.029	5	18	0.949	6.9E-07	2.4E-01	2.7E-03
0.700	0.150	0.025	6	20	0.431	-2.6E-05	2.4E-01	2.0E-03
0.650	0.150	0.057	2	6	4.660	1.7E-06	1.2E-01	1.02E-02
0.650	0.150	0.047	3	8	3.561	-7.6E-06	1.7E-01	6.94E-03
0.650	0.150	0.045	3	8	3.316	9.28E-06	1.5E-01	6.4E-03
0.650	0.150	0.042	3	10	3.065	5.6E-06	1.7E-01	5.5E-03

Table 32. Data from the complete valve model in the flow analysis of the second increment

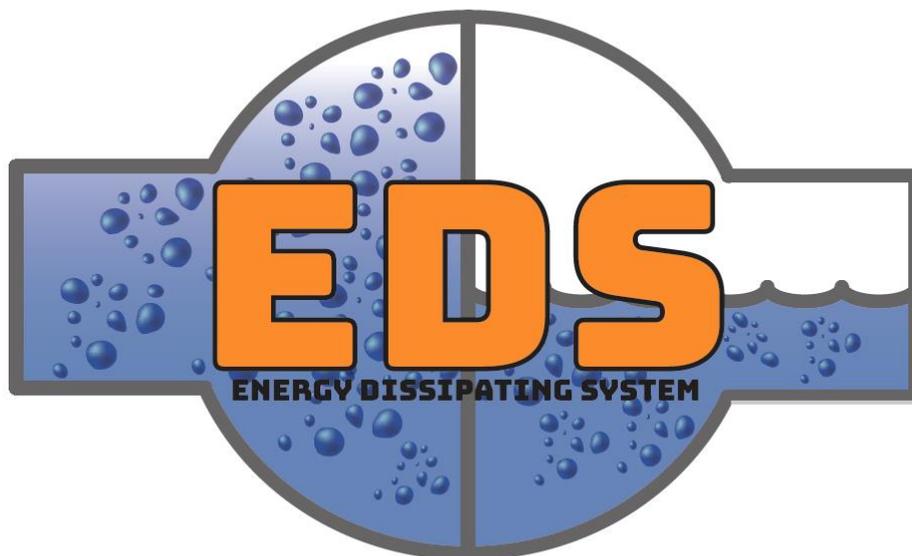


Multiconsult

Design of bypass valve

Technical document: FEM

22.05.2018



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Abstract

Background: The FEM analysis will simulate the internal stresses in the valve body and valve trim from the operating pressure. The simulations is done to ensure that the design is valid for pressure class PN40 and to select a cost efficient material.

Method: The FEM simulations will use the pressure at PN40 when analyzing the stresses in the valve body. It will be done in SolidWorks with the relevant fixtures and restraints applied. After each increment changes may be done to the design to optimize the design. The valve body will be analyzed and the valve trim.

Results: The first simulations showed that there were large internal stresses, over 20 times the allowed limit for the initial material. First fillets was added and the slot for the control mechanism was reduced in size. This reduced the internal stresses, but not enough. In the following simulations, reinforcing blocks were added, and optimized to absorb the stress concentration around the slots. The valve trim simulation showed that the internal stresses were not above the yield strength for the trim material.

Document history

Version	Date	Author	Description
0.00	22.04.18	LH	<ul style="list-style-type: none"> Created the document Added a brief description of the methodology of fem analysis
0.01	27.04.18	LH	<ul style="list-style-type: none"> Added results and pictures of the model
0.02	01.05.2018	LH	<ul style="list-style-type: none"> Scrapped the results because they were wrong Rewrote all the introduction chapters Added 8 Increment chapters with changes to the design
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0.04	07.05.2018	LH	<ul style="list-style-type: none"> Added abstract
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0.06	11.05.2018	LH	<ul style="list-style-type: none"> Added valve trim analysis
0.07	14.05.2018	LH	<ul style="list-style-type: none"> Proofreading
0.08	22.05.18	LH	<ul style="list-style-type: none"> Rewrote Abstract
1.00	22.05.18	OO	<ul style="list-style-type: none"> Proofread Changed reference setup

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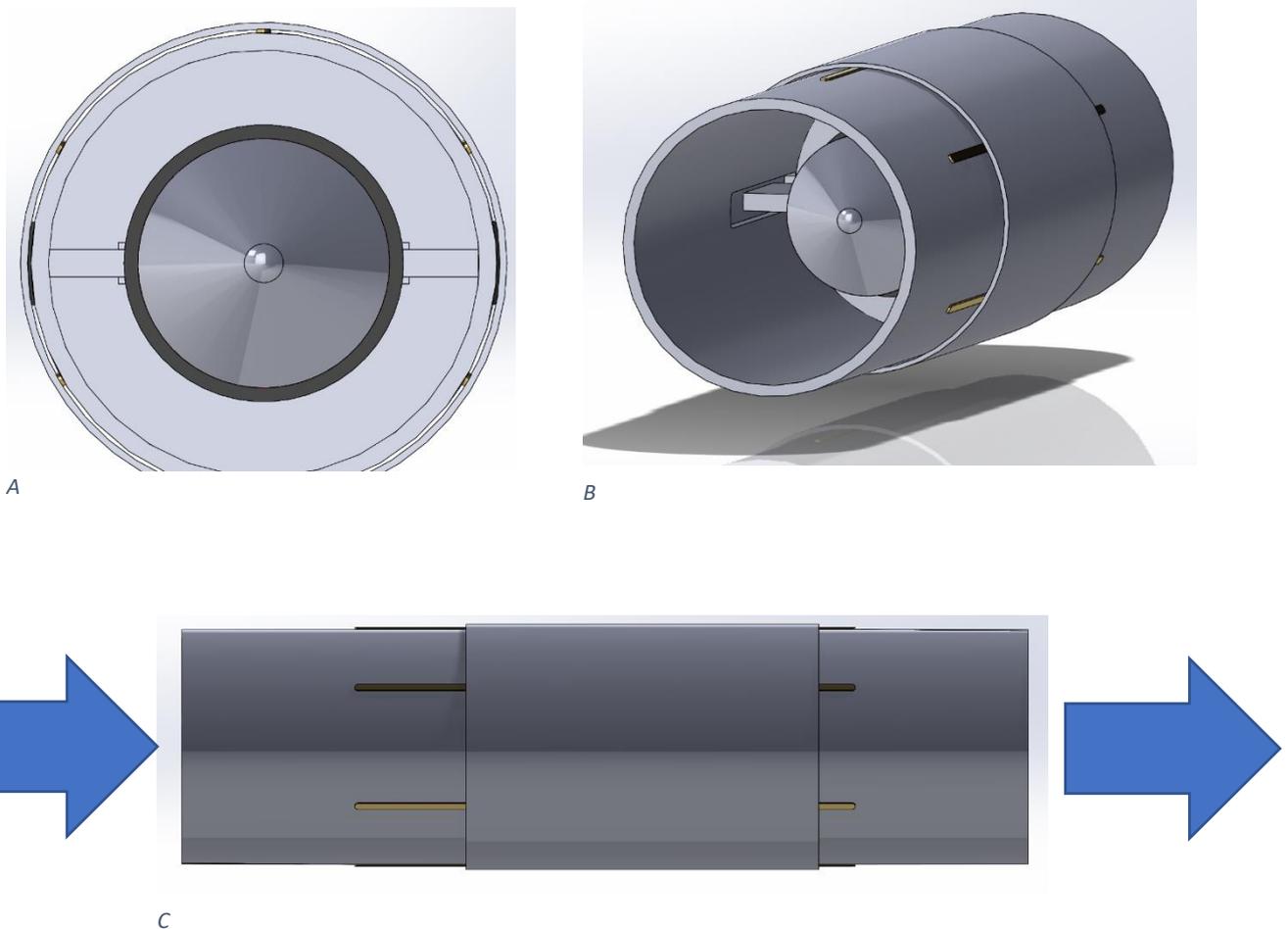
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1 Introduction

The finite element method (FEM) is a numerical method for solving engineering problems. SolidWorks simulation uses FEM to simulate the internal stresses in a part or an assembly of parts when it is subjected to a force. With these results, the design of the valve can be optimized for cost efficiency. It is much cheaper to simulate the forces than to produce a valve and test it. The following chapters will describe briefly how we prepared the model, some critical aspect of FEM in SolidWorks, the forces that were used in the simulations and the results and design changes based on them. Figure 158 shows the valve that will be simulated.



C

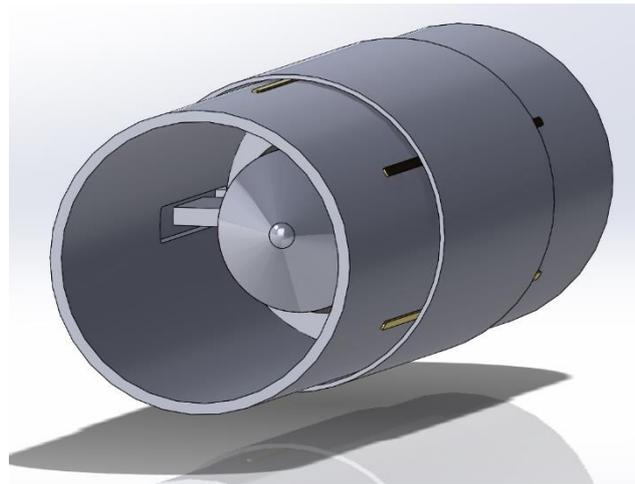
Figure 158: Section A shows the valve front view. Section B shows an isometric view of the valve. Section C shows the valve from the side and the blue arrows indicate the direction of fluid flow

2 Finite element method (FEM)

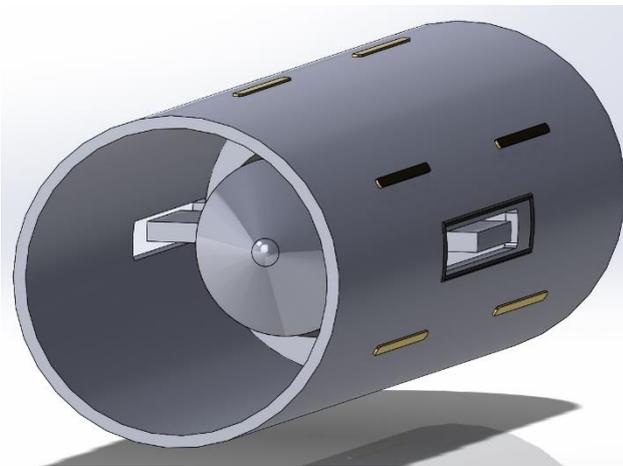
The results from FEM analysis depend heavily on the simulation parameters that the group decides. The goal is to get these parameters to be as similar to a real-life scenario as possible. But it should also be noted that the time usage of the simulation is proportional to the accuracy of the results, more accurate results will take more time. The goal is to find a balance so that the simulations don't take days to complete but still, provide sufficient and applicable results.

2.1 Simplifications

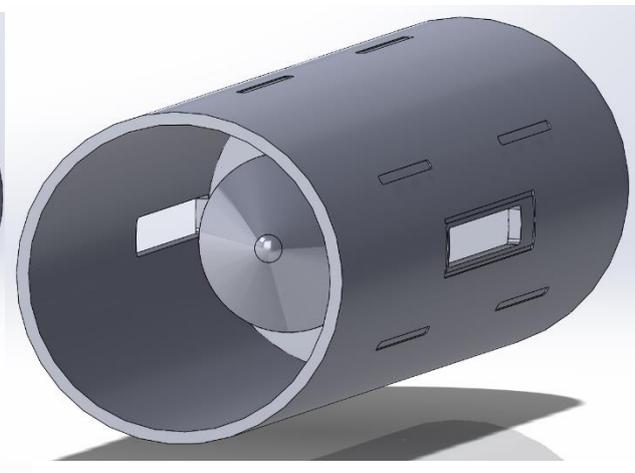
In order to perform finite element analysis, some simplifications to the model have to be made listed below. This is because otherwise the analysis would take an unreasonable amount of time to complete and may not work at all. Some irrelevant parts for the analysis of the valve body are for example the sealings, bronze gliding blocks, studs for flow control and so on. This is illustrated in Figure 159.



A



B



C

Figure 159: Section A shows the valve before any simplifications were made. Section B shows the valve with the control mechanism removed and section C shows the valve with all the necessary simplifications made.

2.2 Forces and fixtures

2.2.1 Forces

The Norwegian Water Resources and Energy Directorate (NVE) states that the valve must withstand 1.5 the rated pressure, and in our case as the valve is designed after PN40 the valve must endure 60 bars. An additional flow analysis (CFD) will be conducted with this pressure as an input. The pressure result from this analysis is then imported into the FEM analysis as the applied force.

In order to make the model “watertight” a capsule was added. The model must be watertight to conduct the CFD. This part will be excluded in the following analysis and will not contribute to the results.

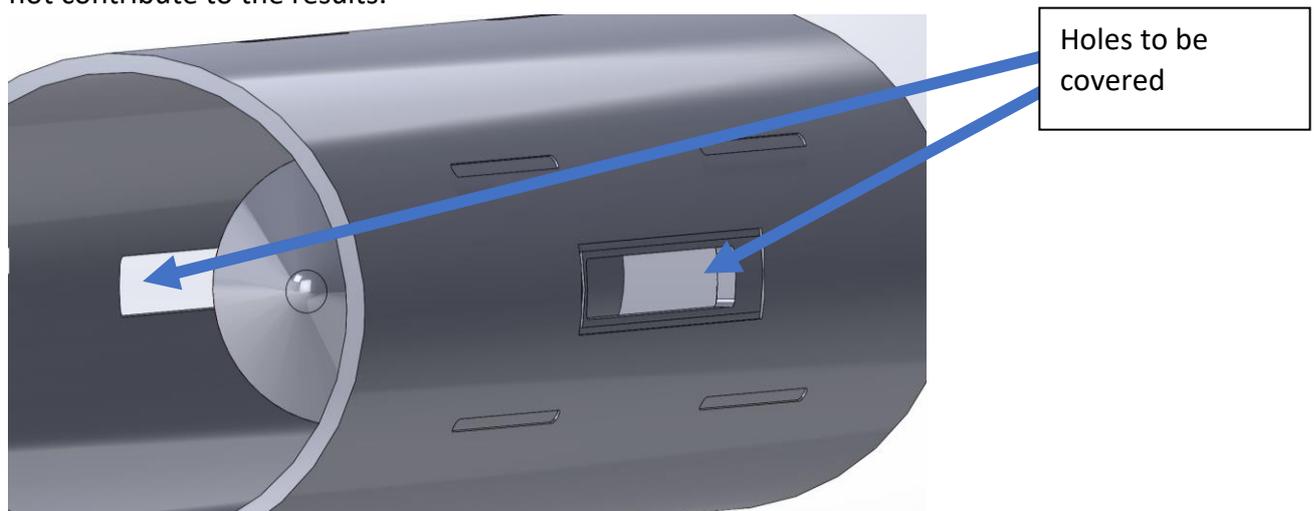


Figure 160: Figure showing the holes in the valve that must be covered

In Figure 161 the model ready for flow simulation can be viewed. The CFD will be conducted the same way as the previous flow simulations in the concept selection phase. An input pressure is specified, in this case 60 bars and an output pressure is specified, environmental pressure. The valve will be fully closed as that is when the maximum pressure is inside the valve.

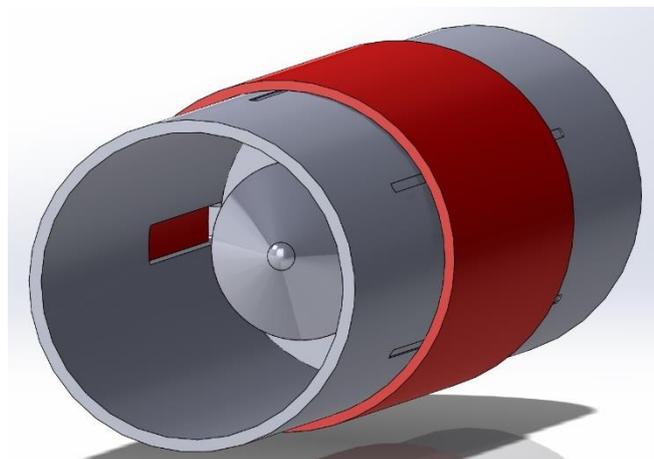


Figure 161: Model ready for flow simulation with 60 bars input pressure to create the forces that will be used to measure the stress in the valve



Figure 162: The pressure that will be used in the FEM analysis. The pressure on the left is 60 bars and on the right it is environmental pressure. The arrows indicate the direction of the flow

Figure 162 shows the pressure that will be applied in FEM. When using this method, the results from FEM will be more accurate than applying the forces manually in SolidWorks.

2.2.2 Fixtures

The valve will be installed by being placed between two flanged pipes and then bolted together. To simulate this fixed geometry was used, displayed as the green arrows in Figure 163. This allows us to only look at the deformation and stresses in the valve itself.



Figure 163: The valve viewed from the side with the fixed geometry shown with the green arrows at each end of the valve.

2.3 Contacts

The global component contact is set to “bonded.” In practice, this means that all the different parts of the simulation will act as they are welded together as this is the case with most of the parts of the valve.

2.4 Material

The material choice can be selected in a separate document (see *Technical document: Material*). All of the materials that will be simulated in this document is a grade of steel, either carbon steel or stainless steel. Initially, the material for the valve body was set to be P235 with a yield strength of 235 MPa, but this can be changed as there are several different grades of carbon steel for pressure plates that have a higher yield strength if necessary.

2.5 Mesh

The mesh is what measures the forces and deformation of the material, and it is essential that we find the balance between accurate results and time usage. There are two types of mesh that are available:

- Standard mesh
 - All surfaces will be meshed first. SolidWorks will fill all surfaces with “triangles” in accordance with specified element size. After this process is done the volume of the material will be filled with tetrahedrons.
- Curvature based mesh
 - The element size will be decided mathematically from a minimum number of elements in a hypothetical circle based on the maximum and minimum set element size.



Figure 164: Meshed model

In our case, the mesh was a combination of the two. The main mesh was defined as standard mesh with an element size of 60mm. This is a high-quality mesh for the size of our model.

Mesh control was then applied to the areas where the stresses were expected to be the highest to get more accurate results shown in Figure 166. Here a curvature based mesh was used. The areas are shown below. The element size is set to 30mm. The most stressful areas are in the slots on each side of the body because they create a weakness in the material.

Mesh Details	
Study name	FEM valve (-Default-)
Mesh type	Solid Mesh
Mesher Used	Standard mesh
Automatic Transition	Off
Include Mesh Auto Loops	Off
Jacobian points	4 points
Element size	60 mm
Tolerance	3 mm
Mesh quality	High
Total nodes	24060
Total elements	11958
Maximum Aspect Ratio	41.626
Percentage of elements with Aspect Ratio < 3	76.2
Percentage of elements with Aspect Ratio > 10	1.79
% of distorted elements (Jacobian)	0
Remesh failed parts with incompatible mesh	Off
Time to complete mesh(hh:mm:ss)	00:00:06
Computer name	

Figure 165: Mesh details. The global mesh size is 60 mm. The aspect ratio is still quite high, and mesh control should be applied at the areas where the largest amount of stresses will be

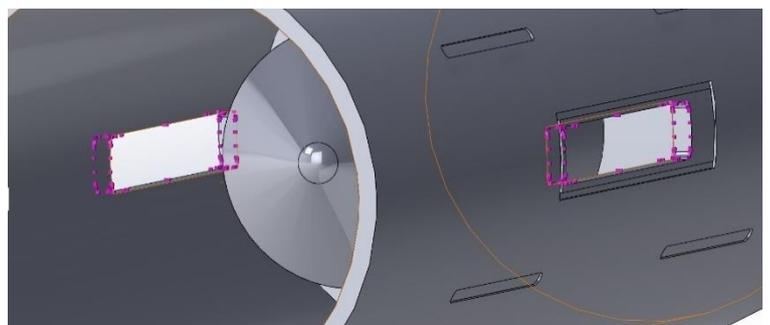


Figure 166: The pink dots indicate the slots where there will be the highest amount of stress. Here mesh control was applied

2.6 Other parameters

2.6.1 Large displacement

Since the size is quite large, the large displacement option had to be used. During a small displacement simulation, all the forces will be applied at the same time but rely on that a number of assumptions SolidWorks makes in terms of the model are correct (Dassault system, 2015).. If not, the simulation can fail or produce inaccurate results. During a large displacement simulation loads are applied gradually and ununiformly in a number of steps up to their full value. This gives a more accurate result but is more time-consuming.

2.6.2 Von Mises stresses

Stress is a measure of internal forces inside a part as a result of applied force (Boyle, 2013). These stresses occur in the x-, y- and z directions. This can result in 6 different stress values which can be a lot to interpret (Figure 167). Von Mises is credited for formulating a way to gather these 6 stresses into one Von Mises stress value. When the Von Mises stress is equal to the stress limit (the limit is usually set to the yield strength of the material) the material will start to yield. The yield strength of a material is the point where the deformation goes from elastic and reversible, to plastic. Once yield is reached the material loses some of its original strength and is unusable. SolidWorks applies this theorem when calculating the resulting internal stresses in a body when a force is applied.

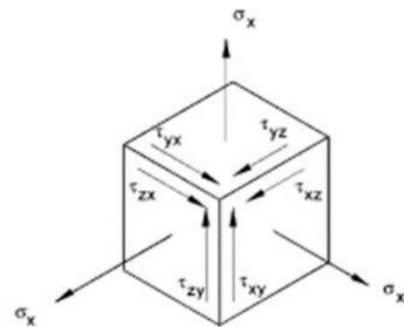


Figure 167: There are 3 normal stresses denoted by sigma, and there are 3 shear stresses denoted by tau (Boyle, 2013)

3 Results

3.1 Stresses and deformation, 1. Increment

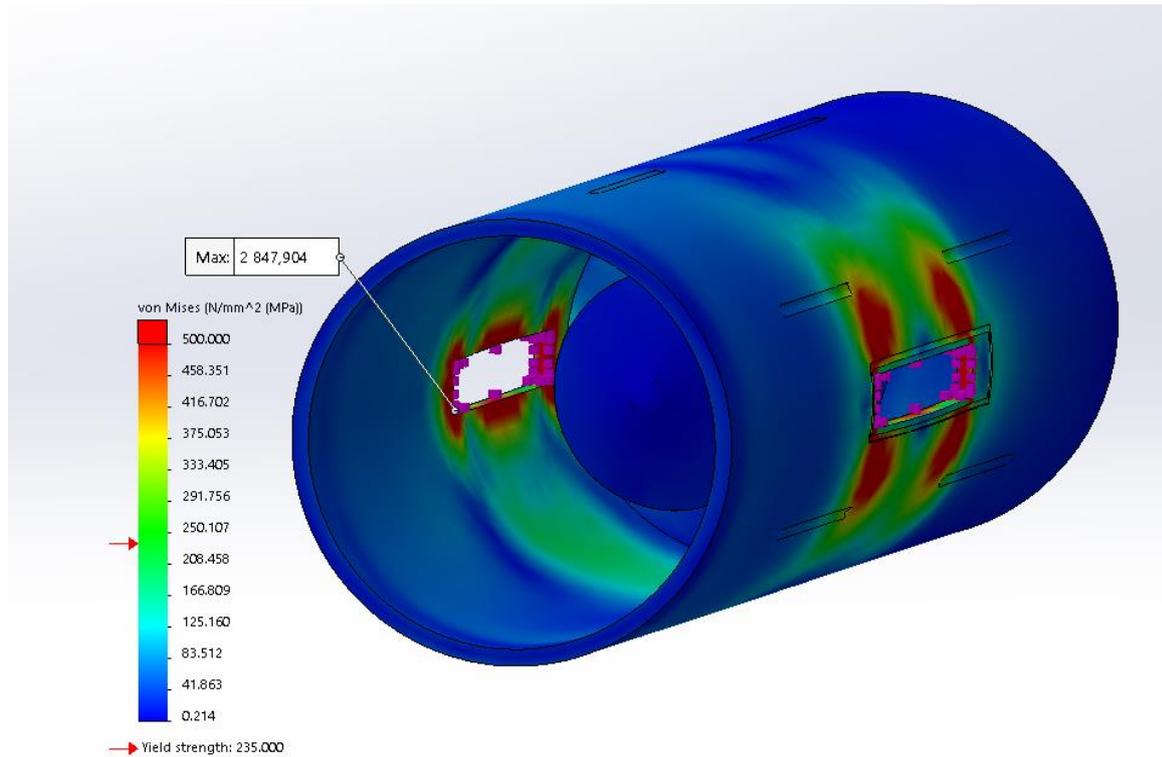


Figure 168: Results from the first analysis. The stresses are far too high to be acceptable.

From the first analysis, the stresses are exceeding the yield strength of the material by ten times shown in Figure 168. Changes must be made to the design or material choice if the valve is to withstand the 60 bars of pressure. The critical areas are in and around the slots for the control mechanism. Since the maximum stress is 2848 MPa, the design must be altered because there are no reasonably cost-efficient materials that can handle this kind of stress. There are three things that can be done:

- Alter the design of the slots, make them smaller and rounder to better distribute the forces
- Reinforce the holes
- Increase the thickness of the material.

3.1.1 Changes made after 1. Increment analysis

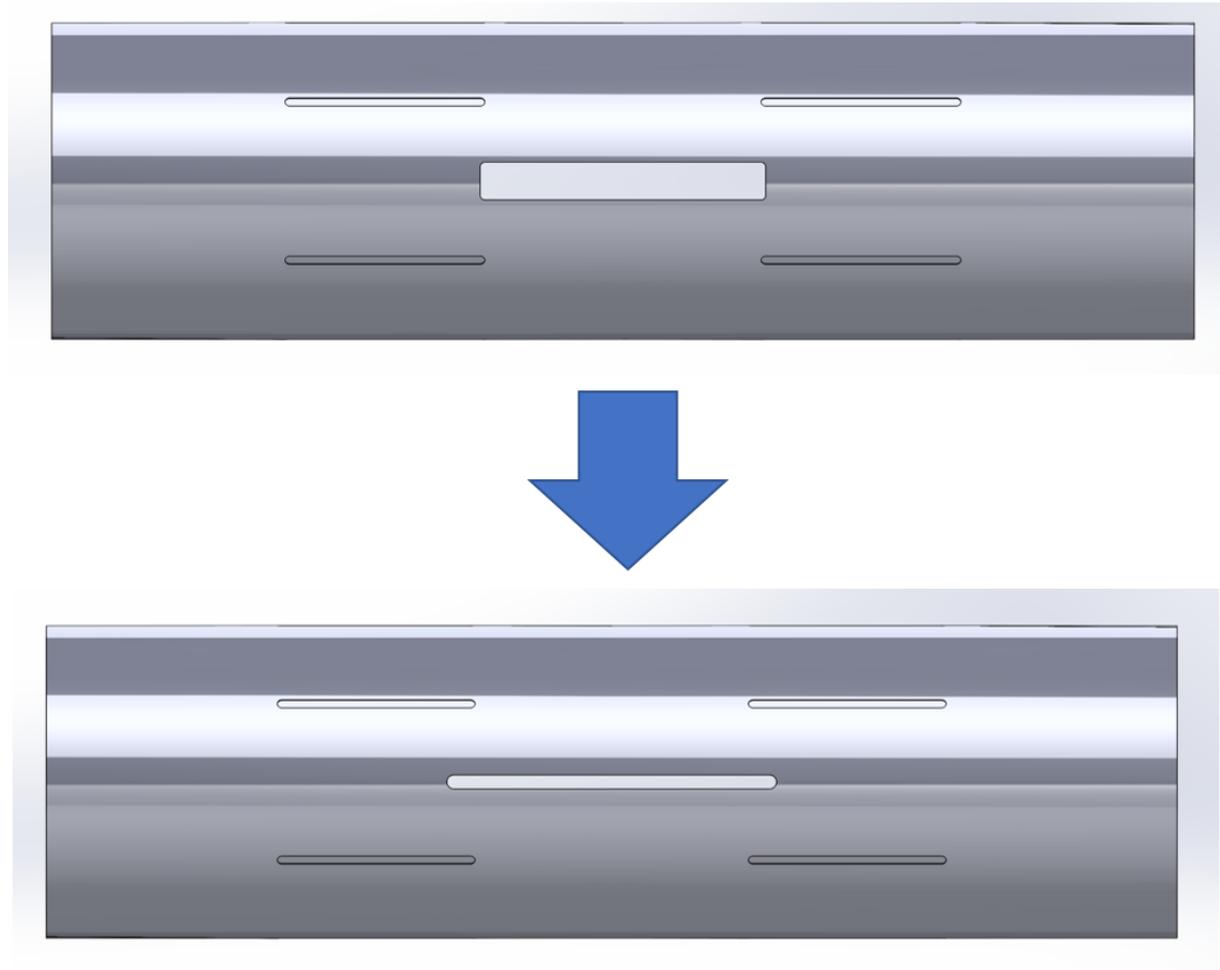
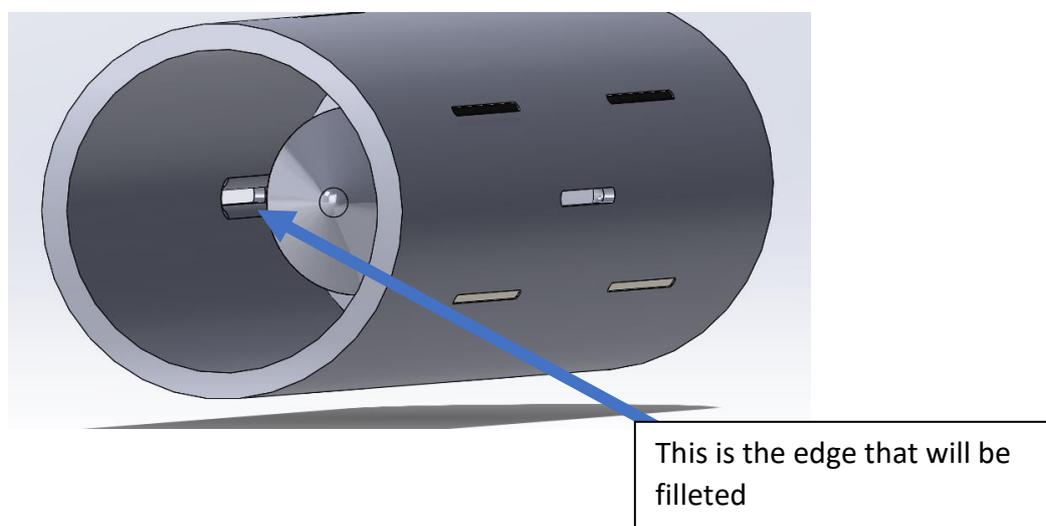


Figure 169: Design change made to the hole. The hole was made into a "slot" with round edges. It was also made thinner and a bit longer to ensure that the control mechanism can open and close the valve

The slot was redesigned to have round edges and thinner shown in Figure 169. The wall thickness was also changed from 21mm to 50mm which may be too high in terms of production cost. Fillets were also applied around the holes to better distribute the forces.



3.2 Stresses and deformation, 2. Increment

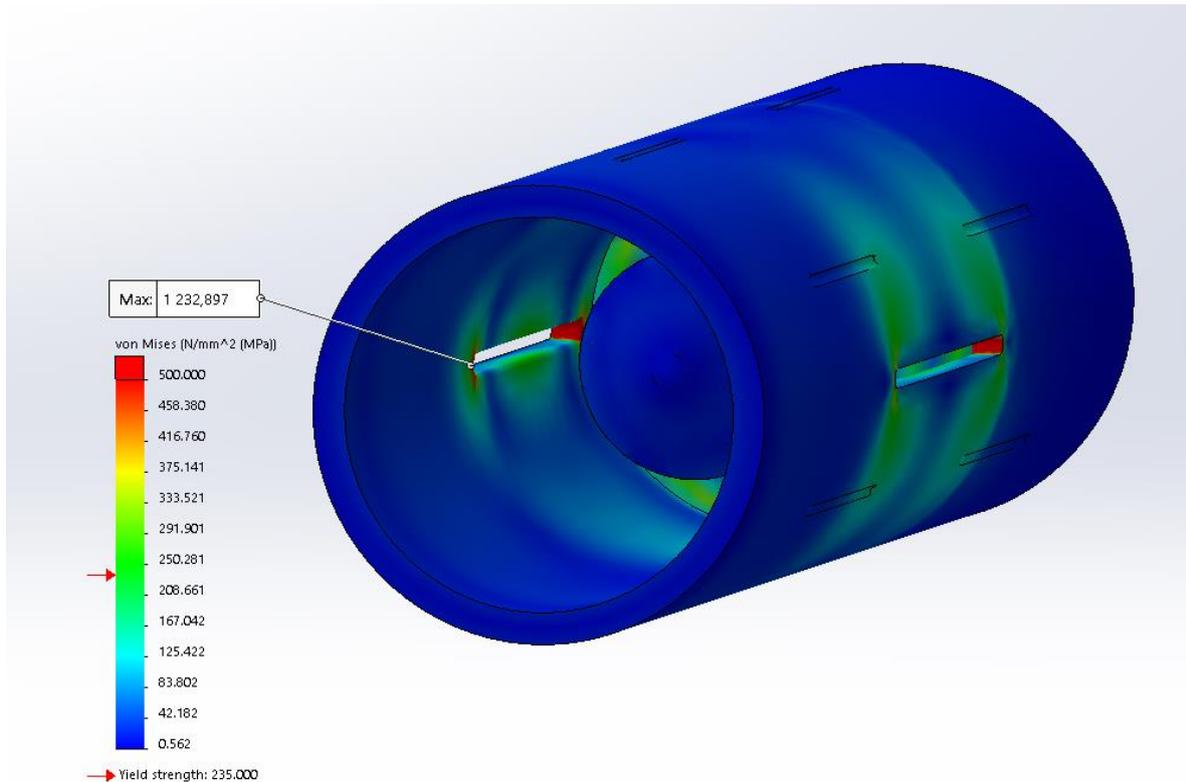


Figure 170: The von Mises stress is cut in half with the changes made. But it is still too high

From Figure 170 the stress is still 5 times as high as the yield strength of the material. The next change that can be done is adding a reinforcement block either inside or outside the valve around the holes. This block can be welded on after the plate has been bent to a cylinder and will thus not increase the cost of manufacturing significantly. The wall thickness can also be increased more, but this will increase manufacturing cost and should be retained as a last resort.

3.2.1 Changes made after 2. Increment analysis

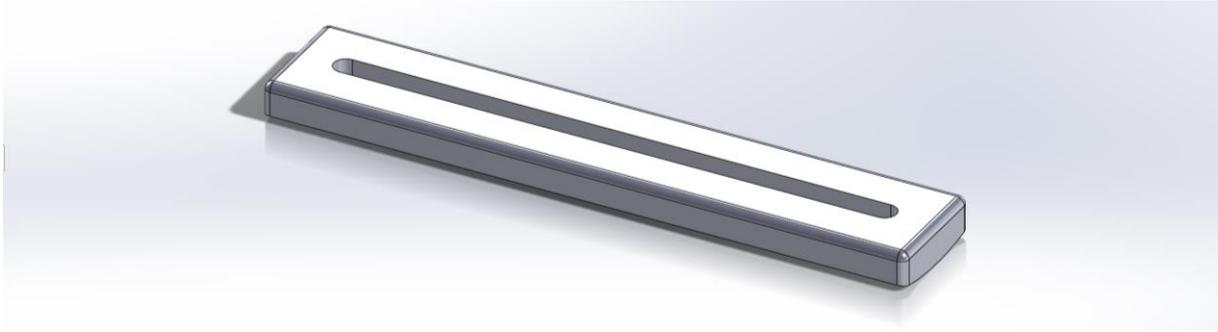


Figure 171: Reinforcement block made for inside valve mounting

Figure 171 shows the reinforcement block that is made for mounting inside the pipe. This will be welded in place under production and still allow for the flow control mechanism to function. Figure 172 shows the reinforcement blocks mounted on both sides of the valve. This will hopefully reduce the stresses around the holes.

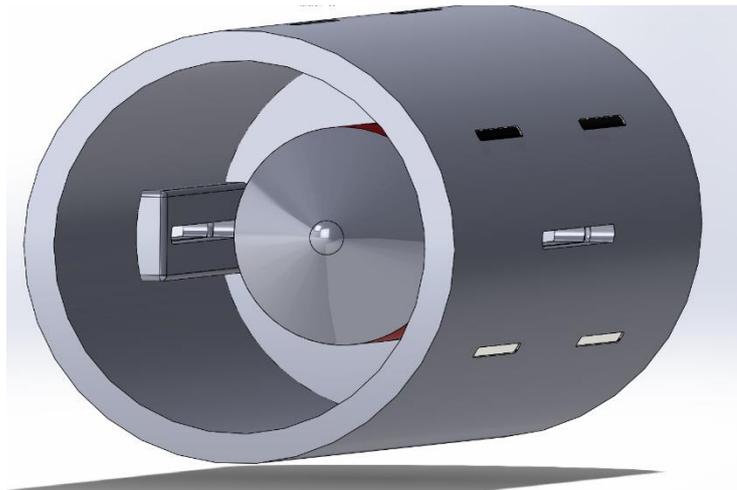


Figure 172: Reinforcement blocks mounted over both slots inside the valve

3.3 Stresses and deformation, 3. Increment

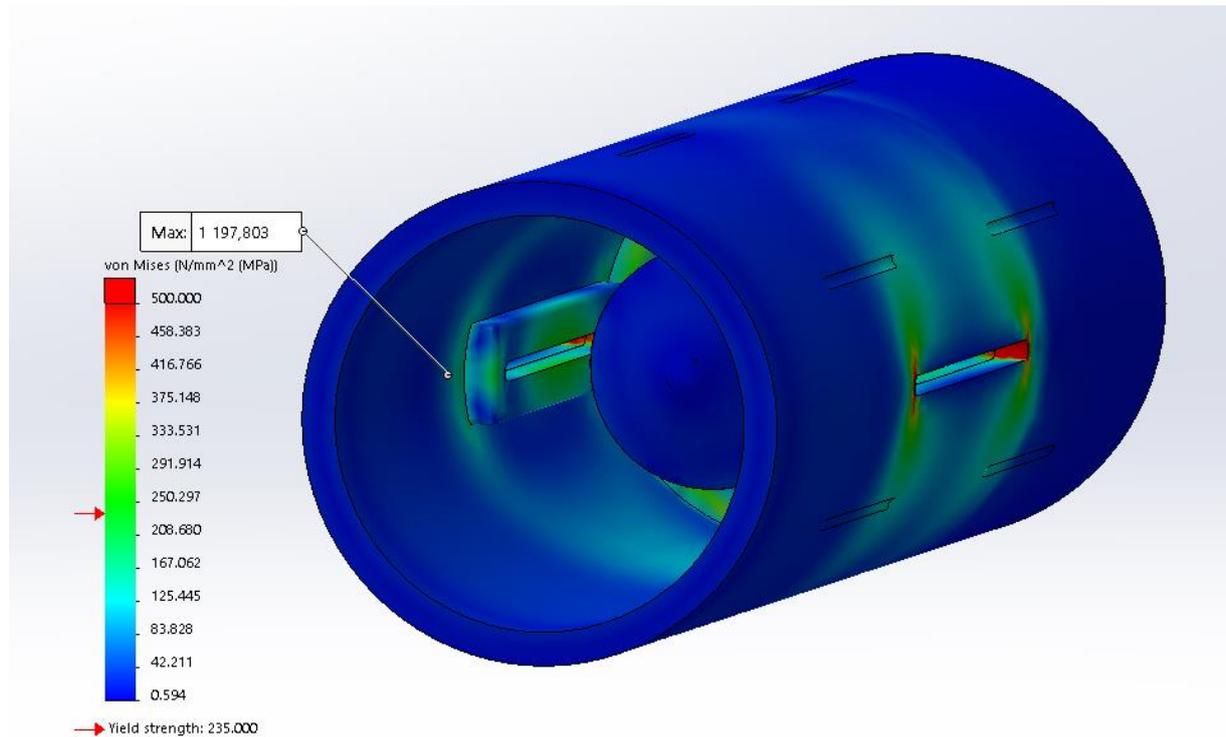


Figure 173: The stresses are reduced by a small amount but is still very high

The von Mises stress is reduced by around 100 MPa which is not enough shown in Figure 173. The reinforcement block will now be mounted on the outside. This will be manufactured the same way as the blocks inside the valve, welded in place after the plate has been bent to a cylindrical shape.

3.3.1 Changes made after the 3. Increment analysis

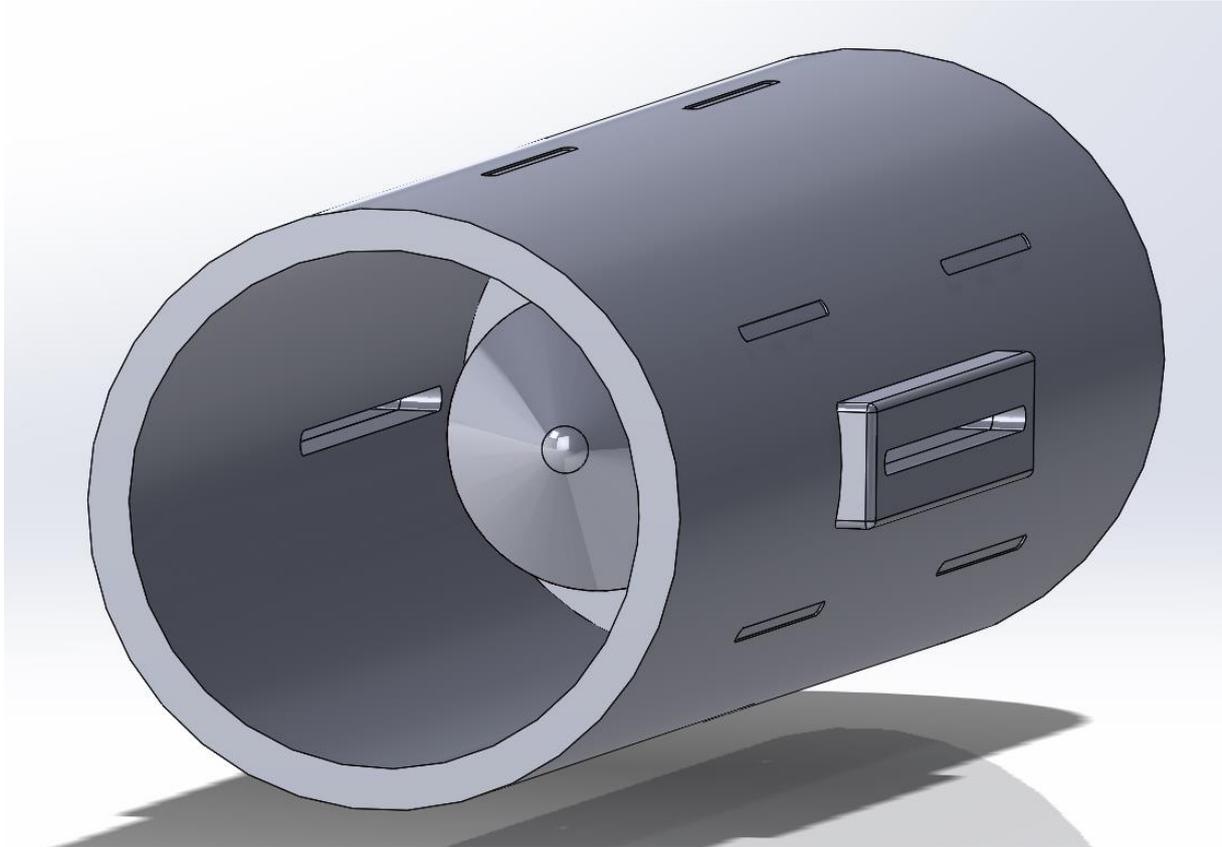


Figure 174: The reinforcement blocks mounted on the outside of the valve.

Figure 174 shows the reinforcement blocks mounted outside the valve. Fillets will be added inside the valve around the holes. These fillets are set to 30mm in radius as a starting point.

3.4 Stresses and deformation, 4. Increment

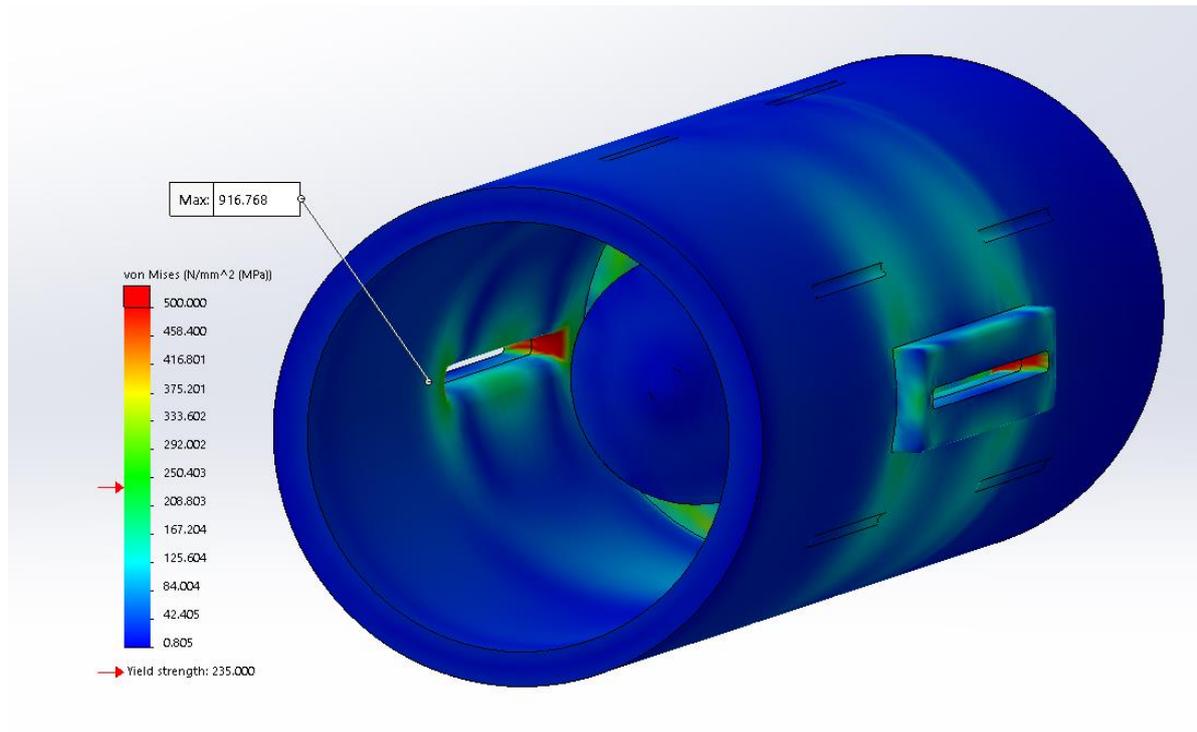
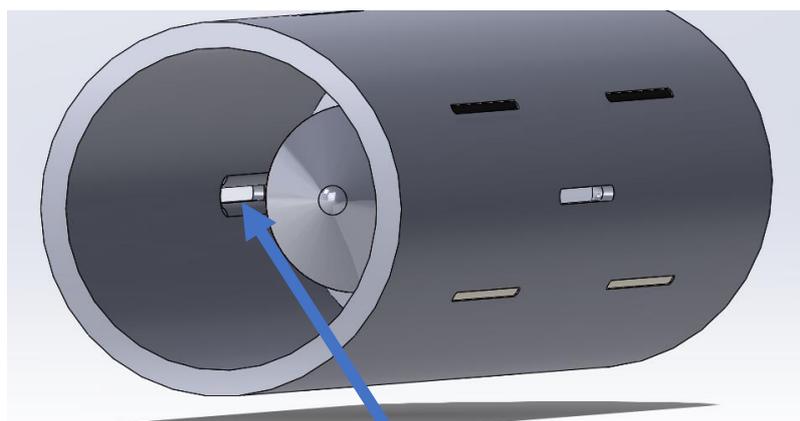


Figure 175: The stress is reduced by around 200 MPa

The von Mises stress is reduced by an additional 200 MPa shown in Figure 175. But it is still too high and not acceptable. There are several more changes that can be made:

- Make the slots for the control mechanism shorter
- Alter the size of the reinforcing block
- Alter the size of the fillet



This is the fillet that will be modified

3.4.1 Changes made after the 4. Increment analysis

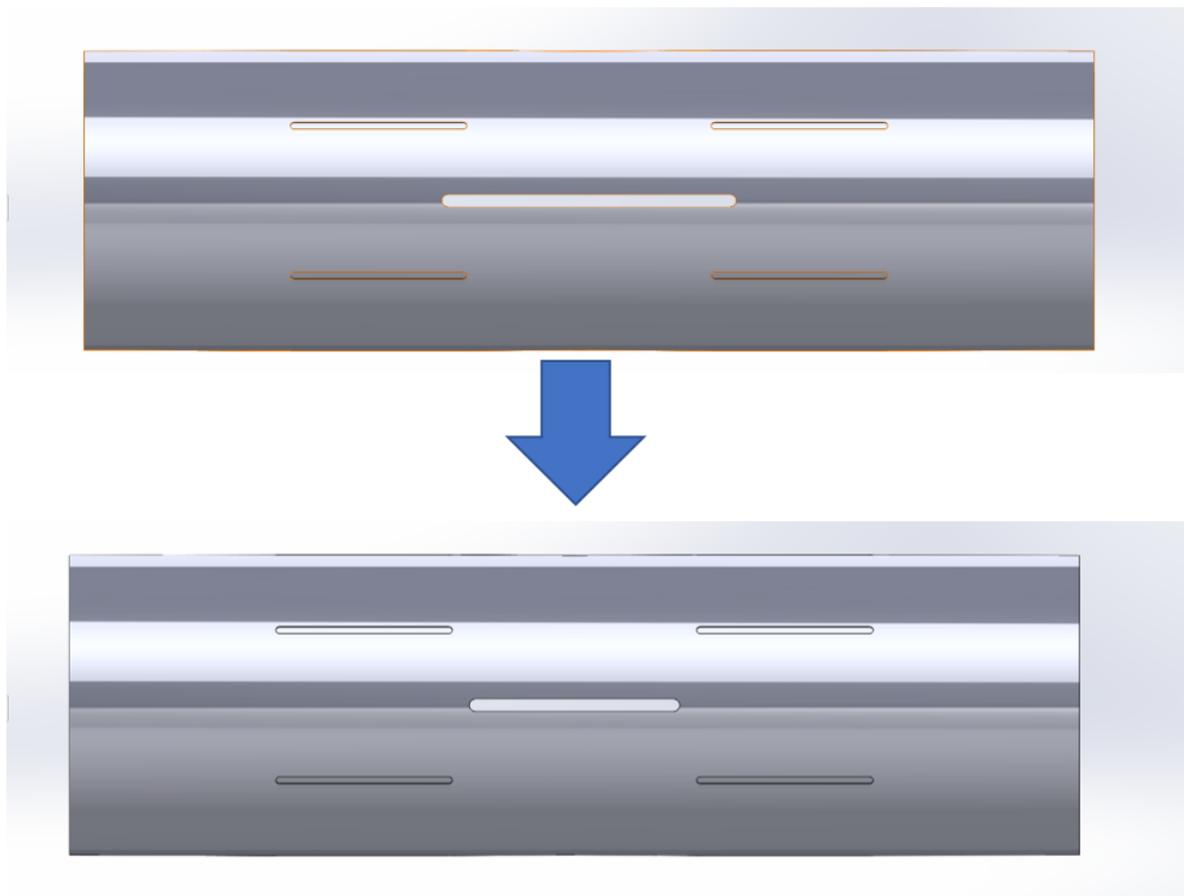


Figure 176: The slot length was altered to make the stresses less

Since the stresses were still too high the slot length was shortened to make the stresses less illustrated in Figure 176. Another thing that will be changed is the size of the fillet. To do this in the most efficient and thorough, SolidWorks design study was used. The design study works by setting a goal (minimize the von Mises stress) and then setting parameters to be changed shown in Figure 177. The fillet size will be changed in increments of 1mm from 25mm to 45mm and then choosing the fillet size that produces the lowest amount of stress.

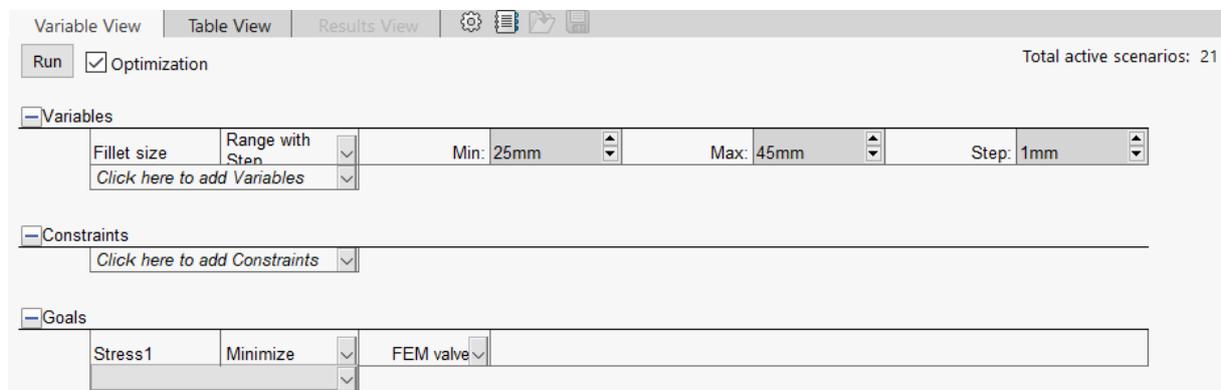


Figure 177: Design study options. The fillet size will be changed from 25mm to 45mm in steps of 1. A FEM analysis will be conducted automatically at each fillet size. This means that 21 analyses will be done. There is no need for constraints as all the fillet sizes will work.

	Units	Optimal	Scenario1	Scenario2
Fillet size	mm	45	25	26
Von Mises	N/mm ² (MPa)	449.08	609.08	576.85

	Units	Scenario3	Scenario4	Scenario5	Scenario6	Scenario7
Fillet size	mm	27	28	29	30	31
Von Mises	N/mm ² (MPa)	550.38	565.84	545.82	508.76	512.27

	Units	Scenario8	Scenario9	Scenario10	Scenario11	Scenario12
Fillet size	mm	32	33	34	35	36
Von Mises	N/mm ² (MPa)	516.23	521.13	492.24	510.49	485.31

	Units	Scenario13	Scenario14	Scenario15	Scenario16	Scenario17
Fillet size	mm	37	38	39	40	41
Von Mises	N/mm ² (MPa)	499.42	491.04	507.66	513.81	489.54

	Units	Scenario18	Scenario19	Scenario20	Scenario21
Fillet size	mm	42	43	44	45
Von Mises	N/mm ² (MPa)	476.08	463.94	489.72	449.08

Table 33: von Mises stress at different fillet sizes ranging from 25 to 45mm.

Table 33 shows how the fillet size relates to the stresses around the hole, larger fillet, less stress. The optimal size from this study is the maximum, 45mm fillet. Another study was conducted from 45mm to 55mm to see if the stress will decrease even further.

	Units	Optimal	Scenario1	Scenario2
Fillet size	mm	50	45	46
Von Mises	N/mm ² (MPa)	408.92	553.57	574.75

	Units	Scenario3	Scenario4	Scenario5	Scenario6	Scenario7
Fillet size	mm	47	48	49	50	51
Von Mises	N/mm ² (MPa)	564.95	564.74	563.93	408.92	462.12

	Units	Scenario8	Scenario9	Scenario10	Scenario11
Fillet size	mm	52	53	54	55
Von Mises	N/mm ² (MPa)	460.32	415.89	415.24	415.11

Table 34: New study with fillet size ranging from 45 to 55

From Table 34 the results look promising, as the optimal fillet size is 50mm. This reduces the stress around the hole to 408.92 MPa. Since the stress is at its minimum at 50mm and increases again at 51mm it is not necessary to run additional design studies for fillet size. The stresses may not be accurate since the flow analysis should, in theory, be conducted for each design change to simulate the right forces, but the design study still serves as a good indication for what fillet size is the best.

3.5 Stresses and deformation 5. Increment

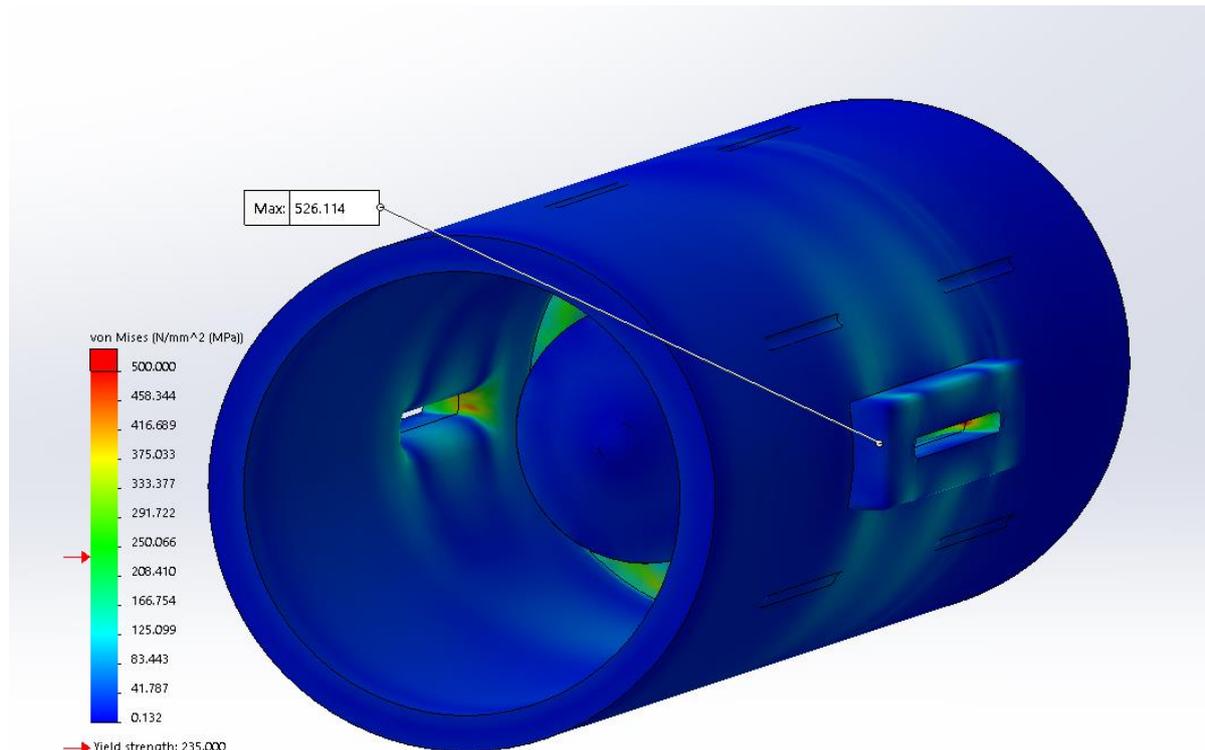


Figure 178: The stress is still too high, even with 50mm fillet and shorter holes. But it is much closer to acceptable than the previous simulations

The von Mises stress is cut in half from the 4. Increment, but is still too high shown in Figure 178. The size of the blocks can be modified to see if that makes a difference to the stresses in the slots. Another thing that should be mentioned is that the material can also be changed. For example, P460 has a minimum yield strength of around 440 MPa at 40 to 60mm material thickness.

3.5.1 Changes made after the 5. Increment analysis

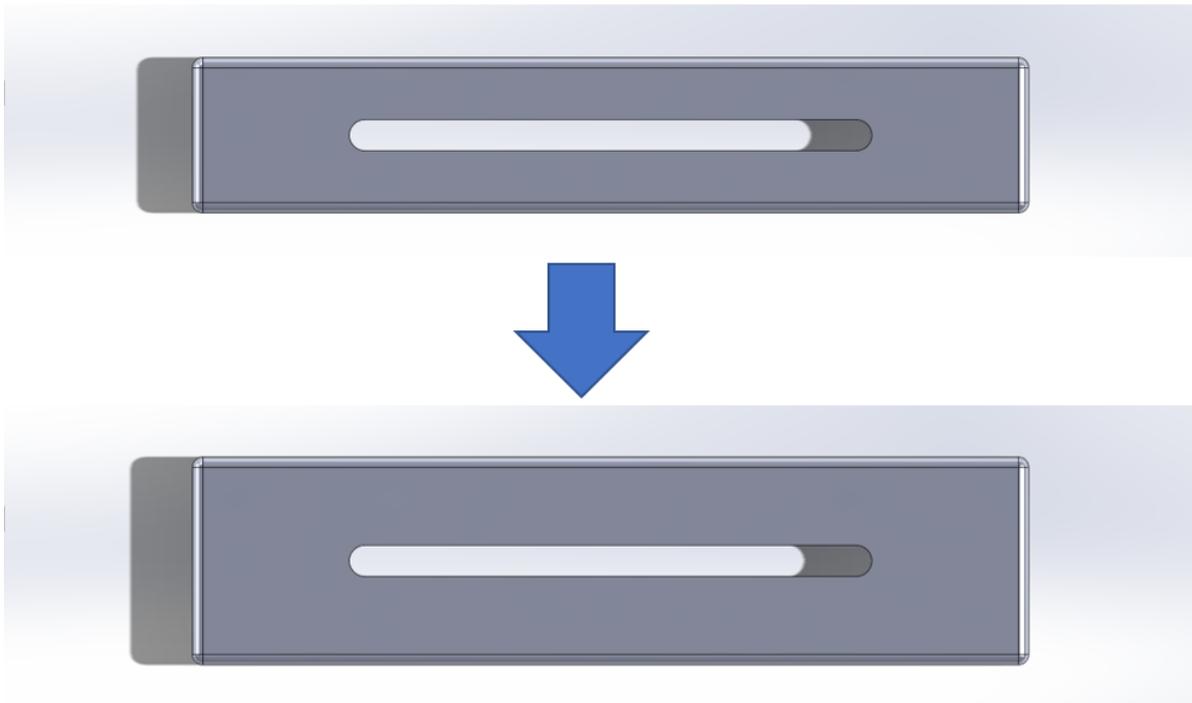


Figure 179: The reinforcement block is made wider by 50mm as a start to see if it makes a difference.

An initial test was done to the figure shown above, and the maximum stress is reduced from 526 MPa to 475 MPa. The final width of the reinforcing block is set to 350mm.

3.6 Stresses and deformation 6. Increment

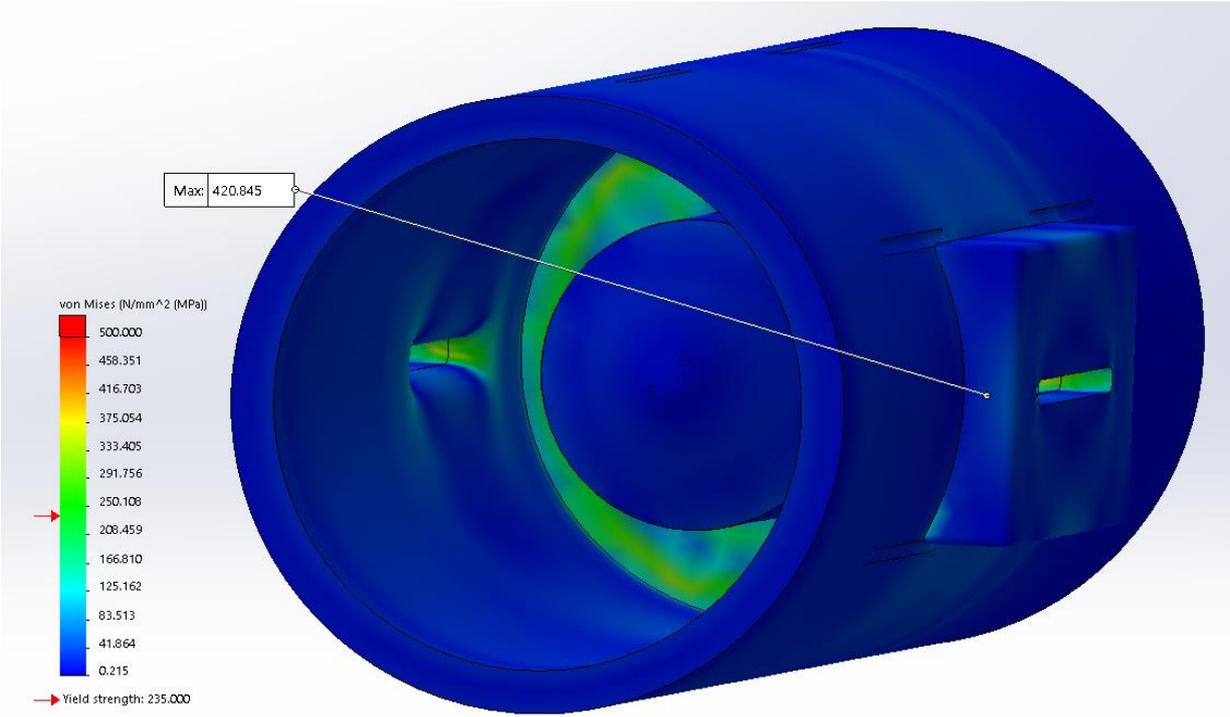


Figure 180: After increasing the width of the reinforcing block the stress was reduced to 420MPa which is within the yield strength of P460.

The design shown above can handle the stress the pressure inside the valve causes without compromising the control mechanism. One problem is that the reinforcing block must be welded to the valve body and if it is as big as in Figure 180 it may not work.

3.6.1 Changes made after the 6. Increment analysis

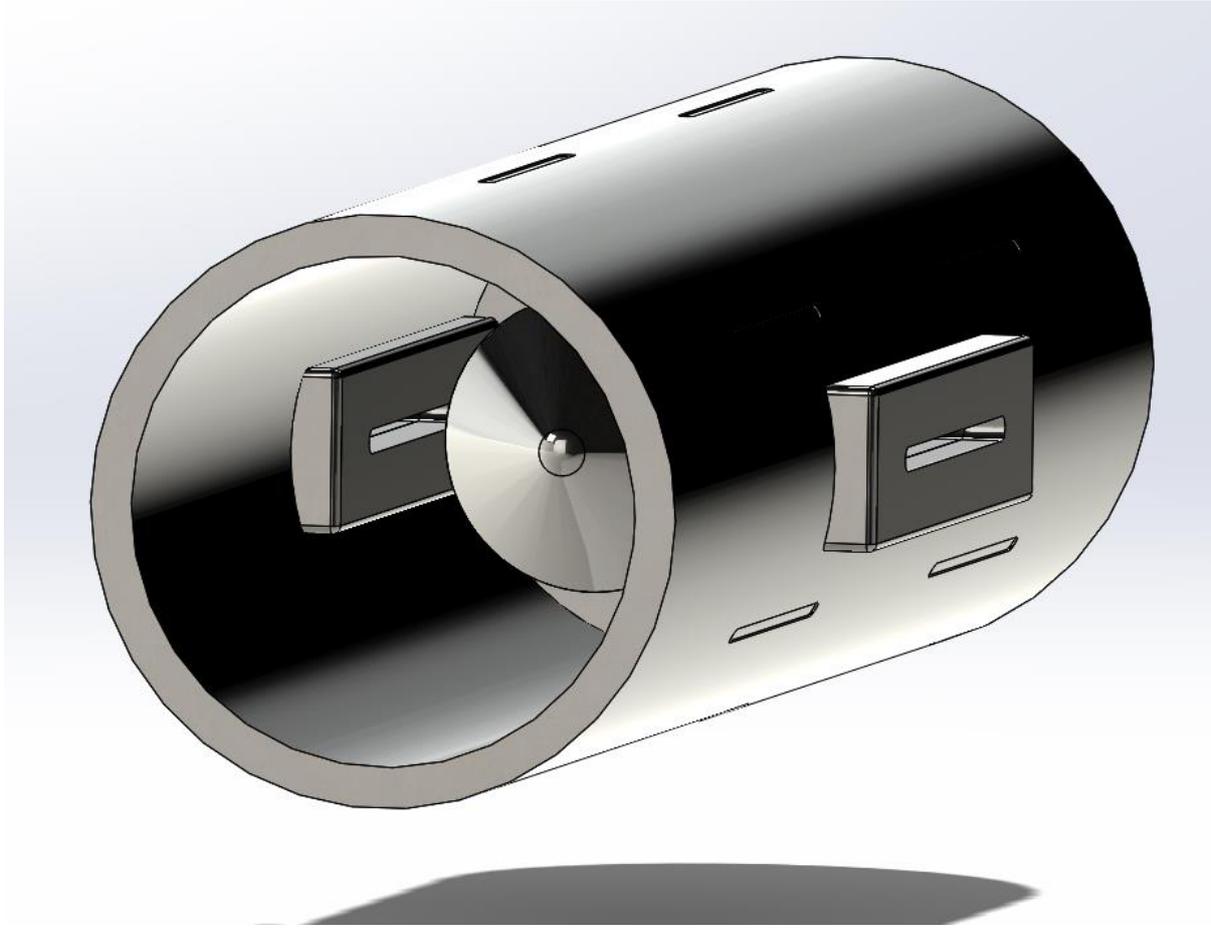


Figure 181: Reinforcing block mounted both inside and outside the valve

Since the width of the block became too large to weld properly in place the block was mounted both inside and outside the valve and the width decreased from 300 to 200mm shown in Figure 181.

3.7 Stresses and deformation after the 7. Increment

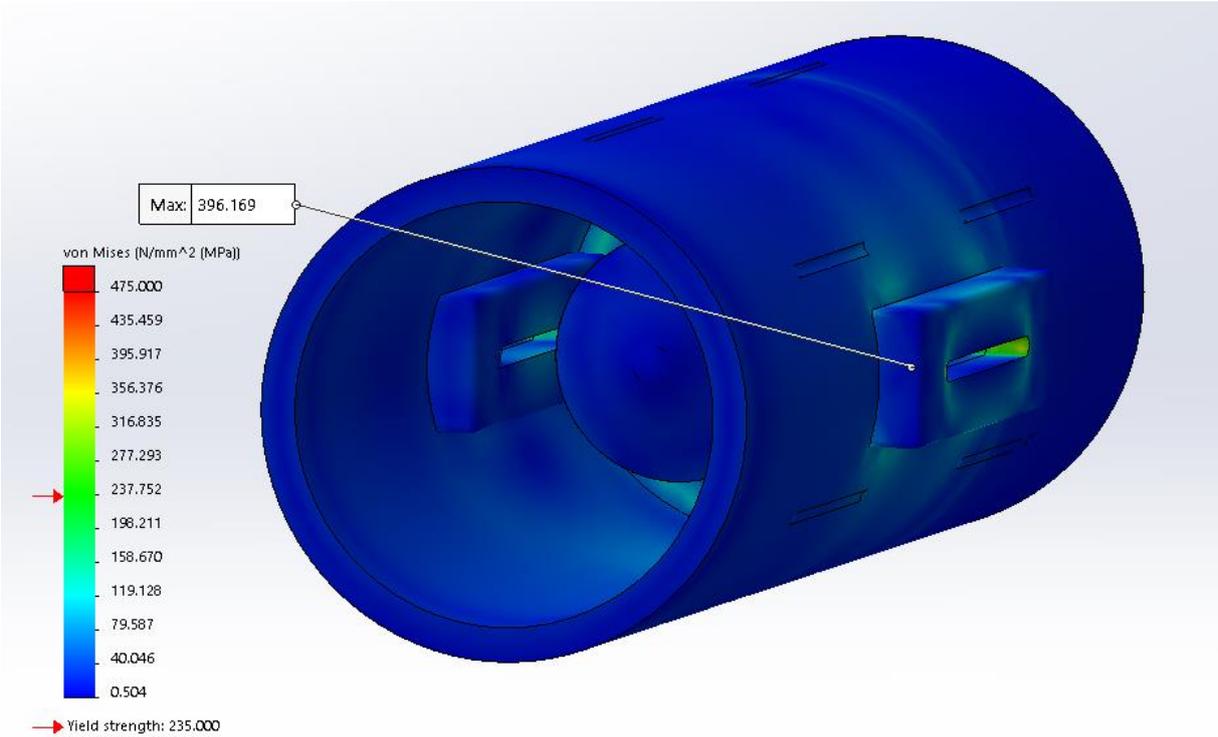


Figure 182: The von Mises stress is now at an acceptable level for P460 steel.

From Figure 182 the von Mises stress is now at an acceptable level for P460 steel at 396 MPa, but there is still a problem in terms of welding the blocks in place. The most optimal configuration is if the blocks themselves is one piece and is then welded in place in precut holes in the pipe.

3.7.1 Changes made after the 7. Increment

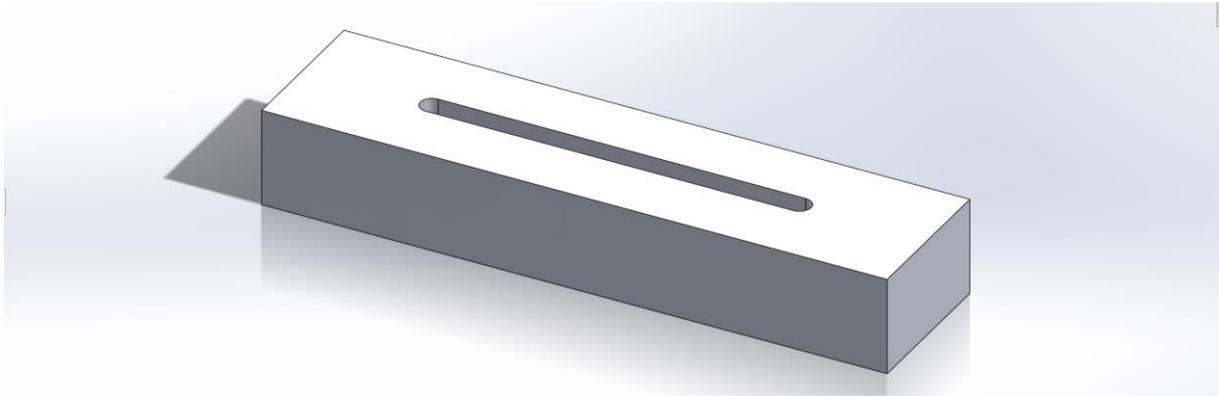


Figure 183: One solid reinforcement block instead of two separate

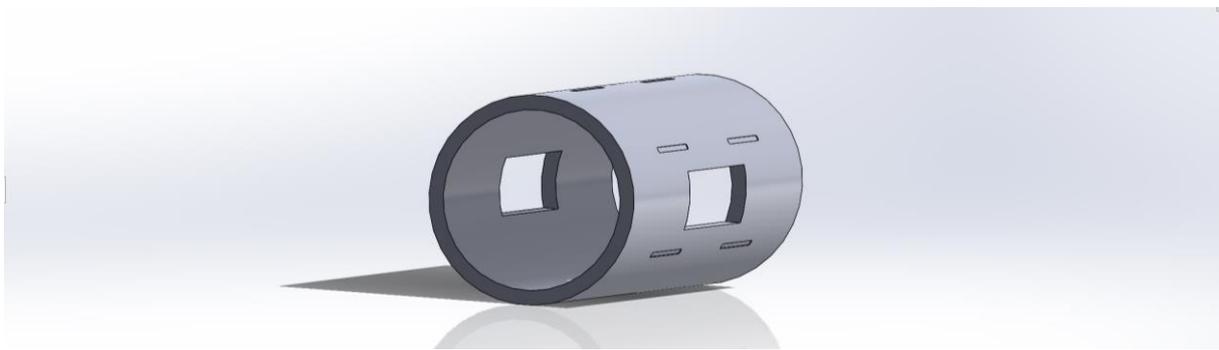


Figure 184: Larger holes for the reinforcement blocks

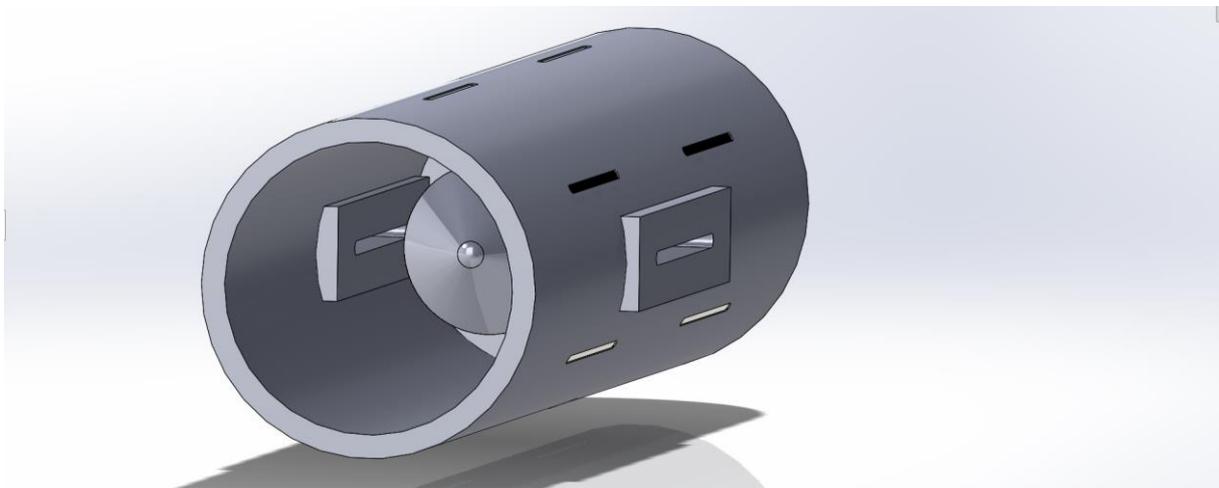


Figure 185: View of the reinforcing blocks mounted in place.

The reinforcement block was made into one piece that will be mounted on both sides and welded in place shown in Figure 183, Figure 184 and Figure 185. This solves the issue of welding, and since it is only one part the stresses should theoretically go down.

3.8 Stresses and deformation after the 8. Increment

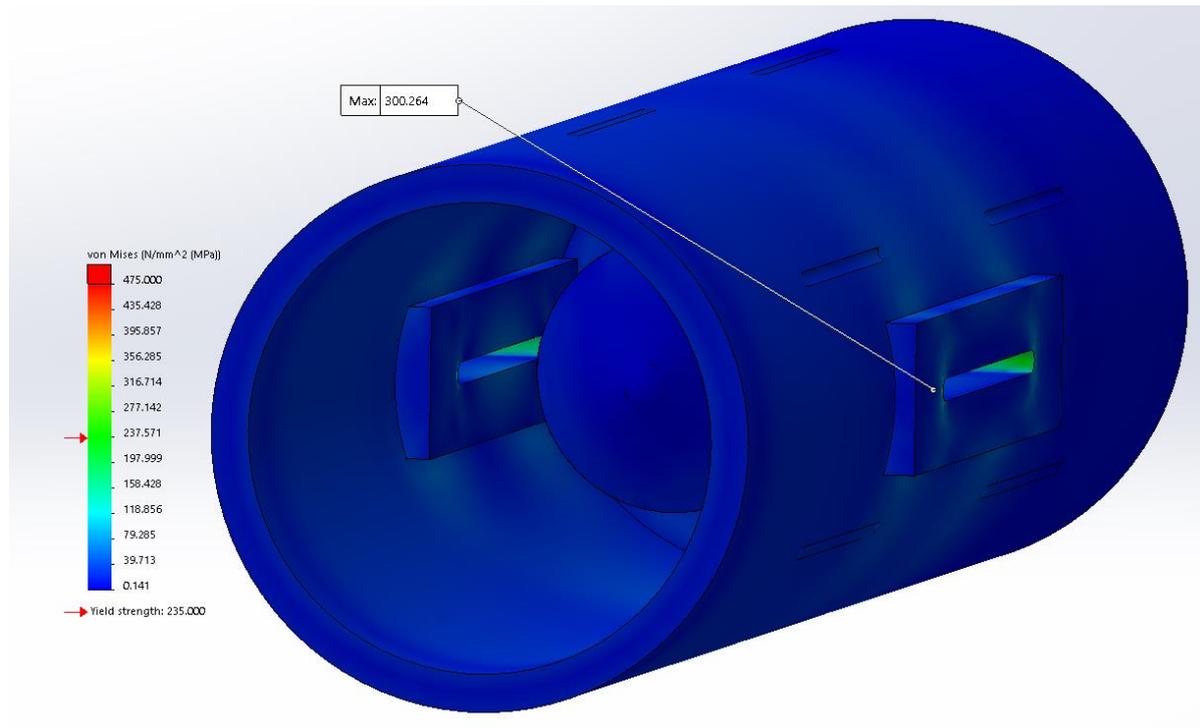


Figure 186: When using a solid block instead of two the stresses in the joints went down drastically. From 396 MPa with two more significant blocks down to 300 MPa with a smaller single block on each side.

The results from FEM when using a single reinforcing block instead of two is very promising. The stresses went down to a respectable 300 MPa which is well within the yield strength of P460.

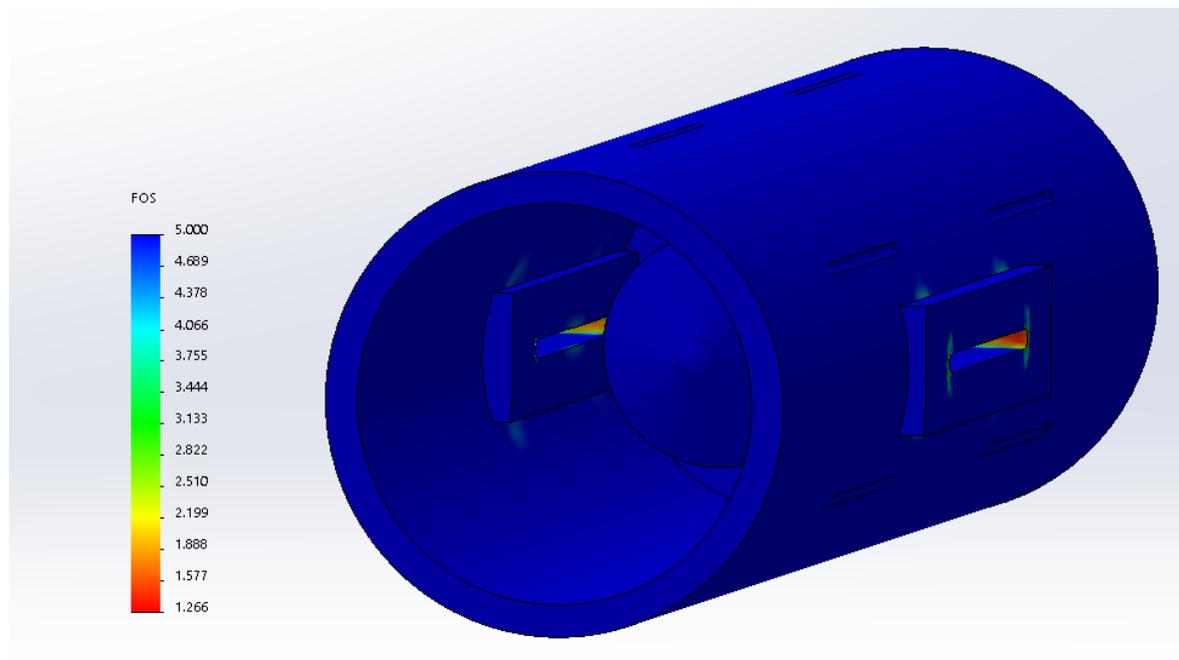


Figure 187: Factor of safety plot. The factor of safety over 5 is in the darkest blue. The lowest factor of safety is as anticipated inside the slots.

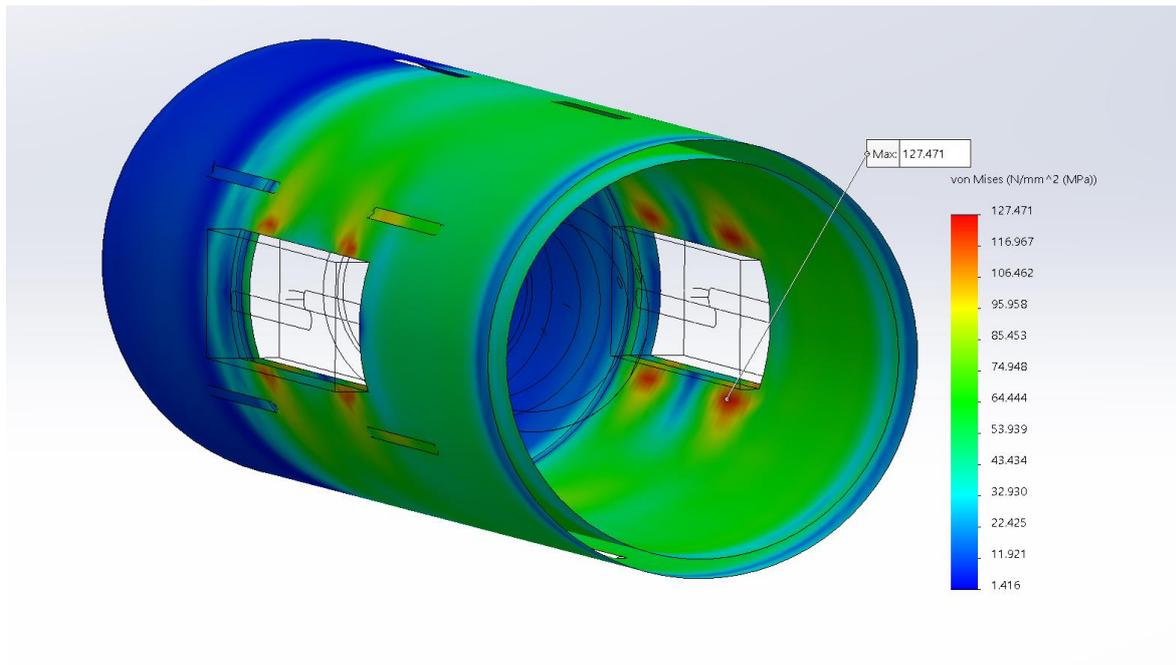


Figure 188: The simulation after the wall thickness was decreased from 50mm to 30mm. This was done because with 50mm wall thickness the maximum stress in the valve body was around 80 MPa and there was room for optimization.

The maximum stress in the valve body was 80 MPa, so the wall thickness was reduced from 50 to 30mm. Figure 188 shows the maximum stress in the valve body after the wall thickness was decreased. The wall thickness was decreased back to the initial 25mm in Figure 189.

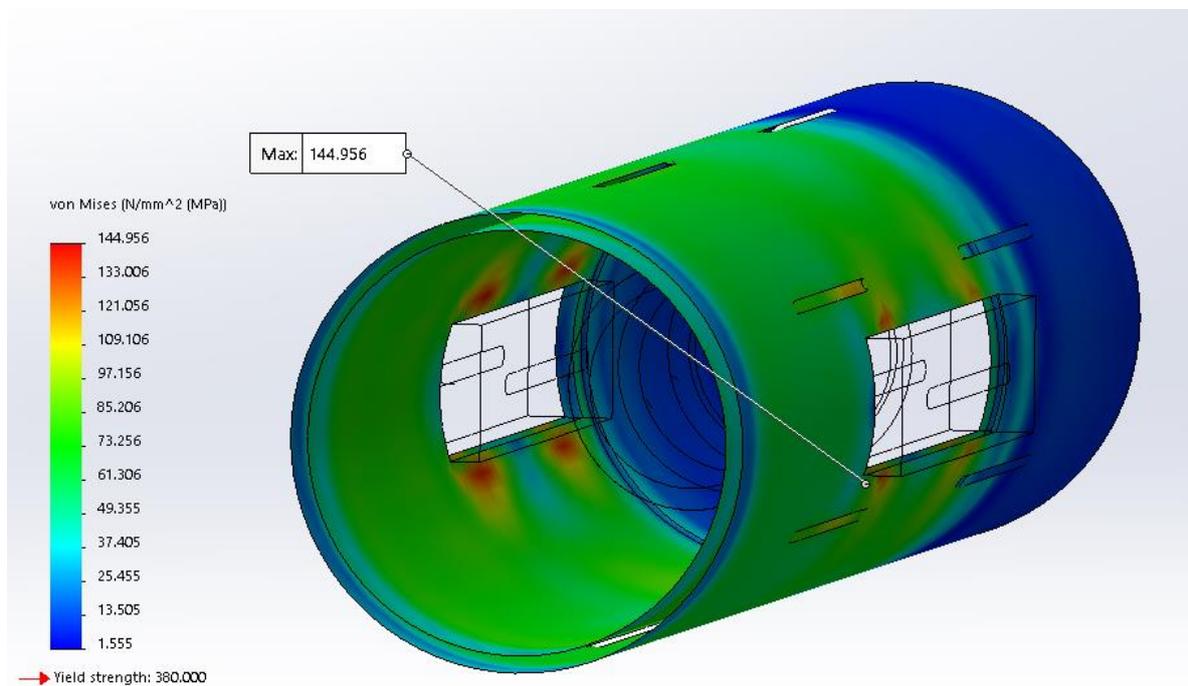


Figure 189: The wall thickness is reduced even further, down to 25mm. The stresses in the valve body are still lower than the yield strength of the material.

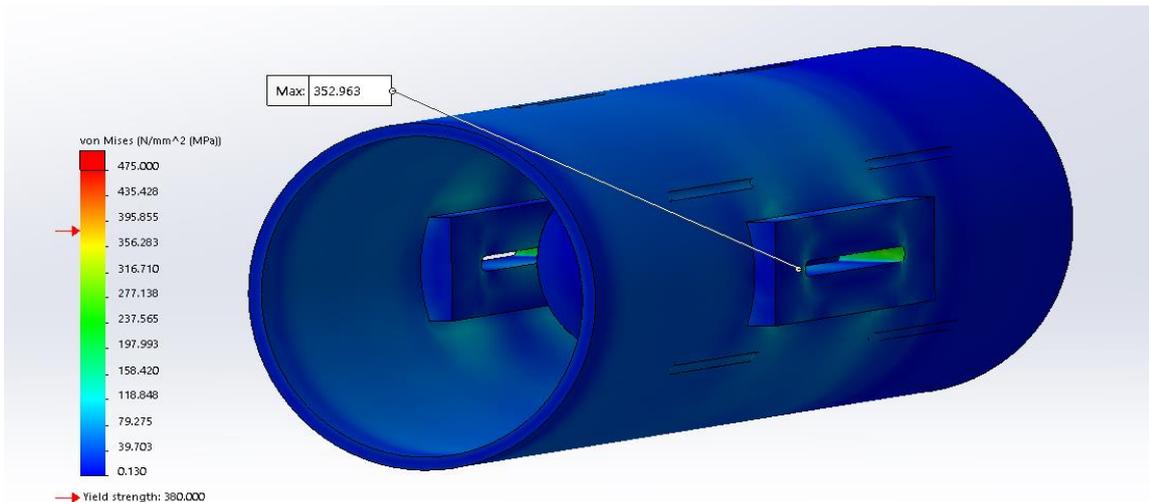


Figure 190: This is the stresses in the reinforcing block when the wall thickness of the valve body is 25mm. This is an acceptable amount

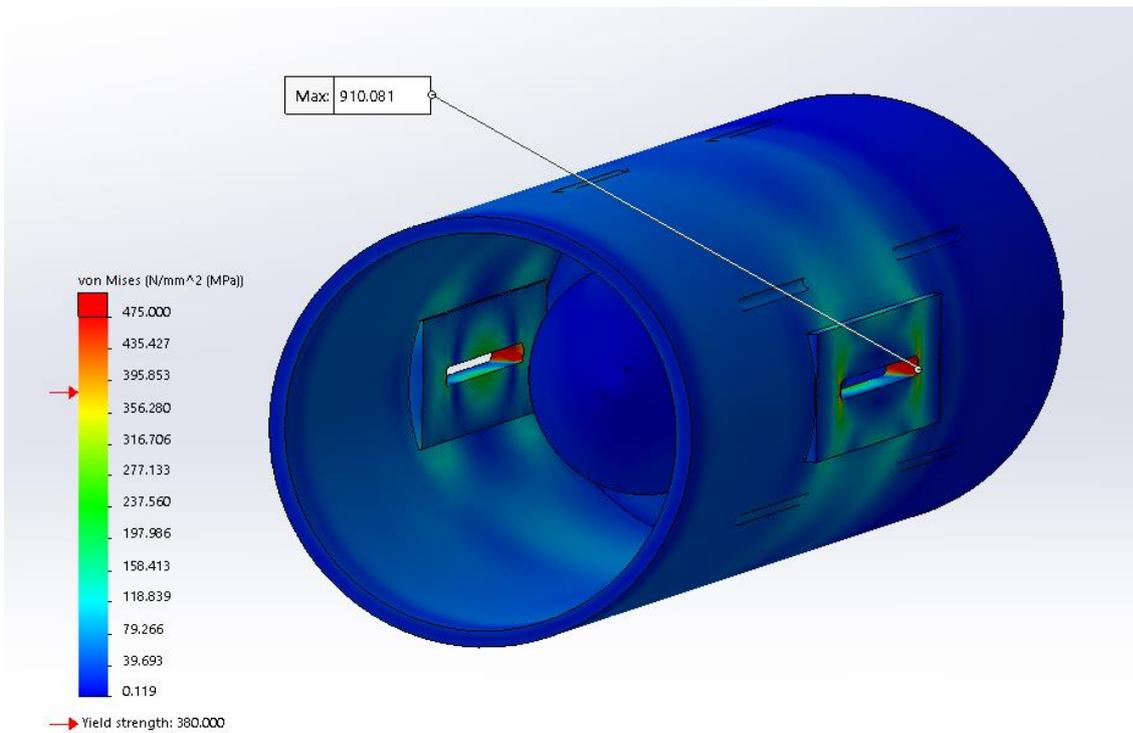


Figure 191: The thickness of the reinforcing blocks is at the minimum valve at 125mm. In the picture a thickness of 50mm was tried and the stresses are far too high.

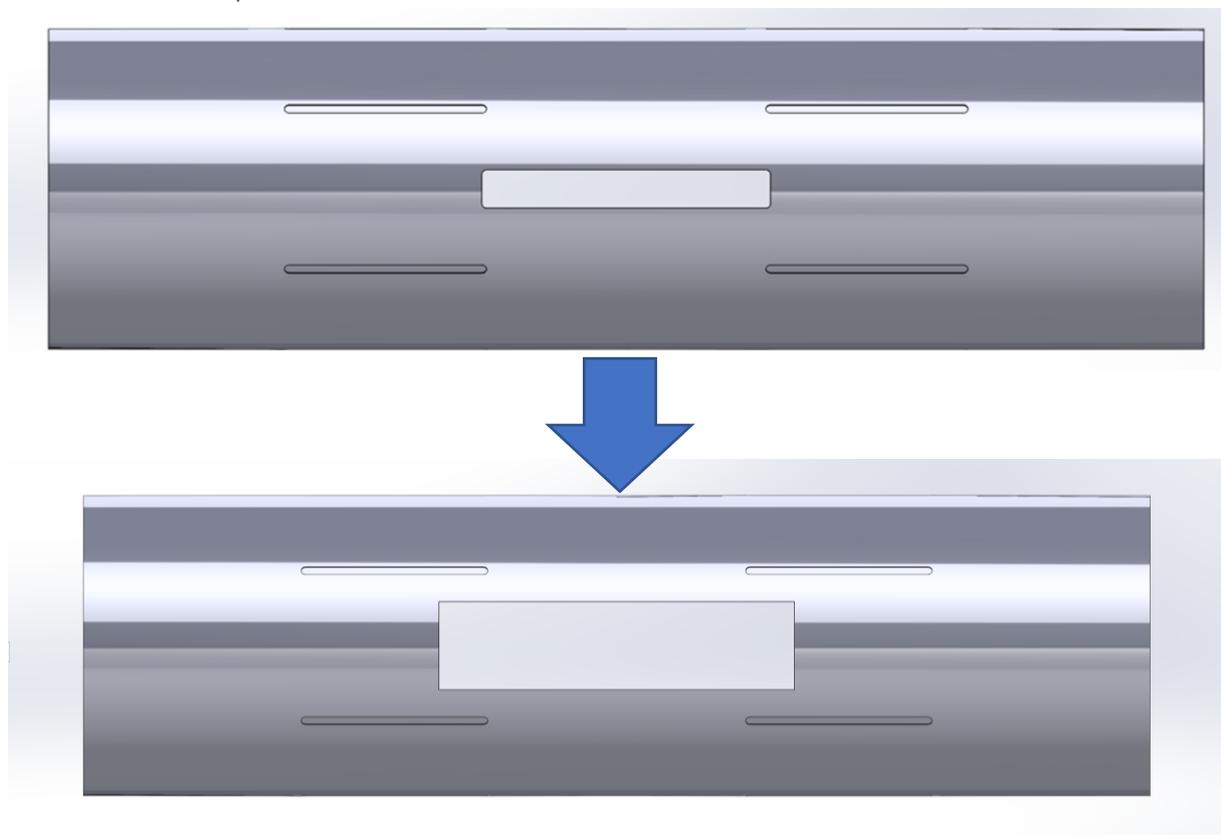
4 Conclusion

After 8 Increment of testing and analyzing a solution was found. The problem with having the slots for the control mechanism is that they create a weakness in the valve body. The solution was to make the holes larger and then weld a single reinforcing block in the hole. This makes the pressure from inside the valve divide over a larger surface and not concentrate inside the slot. The production process will be pretty much the same as the initial design, except for that two larger rectangular holes has to be cut instead of two smaller slots. The blocks must also be considered in the production document.

4.1 Results from simulation

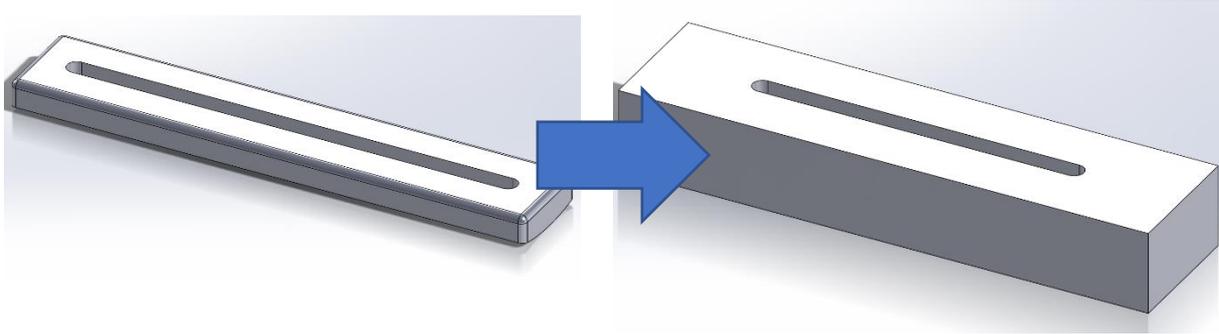
Here are the changes done to the part displayed.

4.1.1 Valve body



- The hole was changed to fit a reinforcing block
- The wall thickness was changed during the analysis, but after adding the reinforcing blocks, it was changed back to the initial 25mm.

4.1.2 Reinforcement block



- The reinforcing block was first made as an add-on outside the valve
- Changed to fit inside the pre-cut hole in the valve body (*see Technical document: Assembly*).

5 Valve trim FEM analysis

The valve trim must also be simulated to check if it can withstand the forces. This will be done the same way as the valve body; CFD with input of 60 bars and importing the pressure results into FEM. The material in the trim is stainless steel to withstand better the abrasives that can be in the water and cavitation.

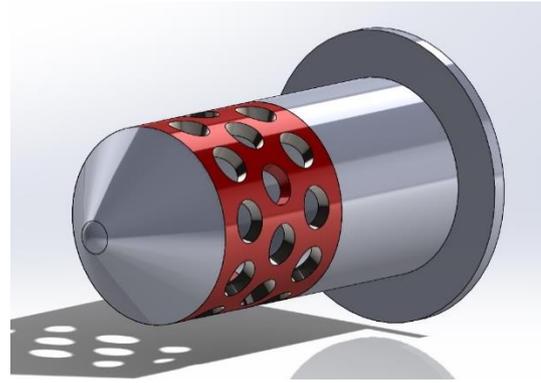


Figure 192: This is the valve trim to be simulated

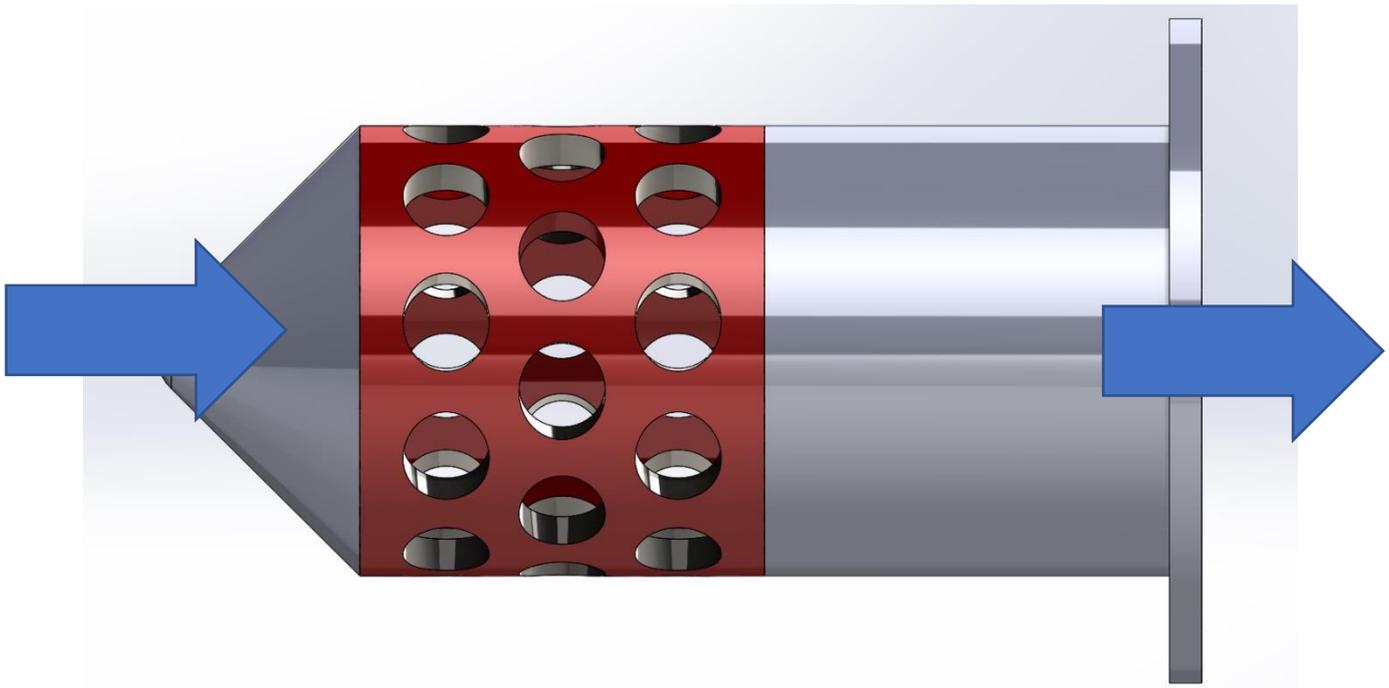


Figure 193: The valve trim will be mounted inside the valve body as can be seen in the previous figures in chapter 3. The water will flow through the perforated in the direction of the blue arrows.

5.1 Stresses in the valve trim

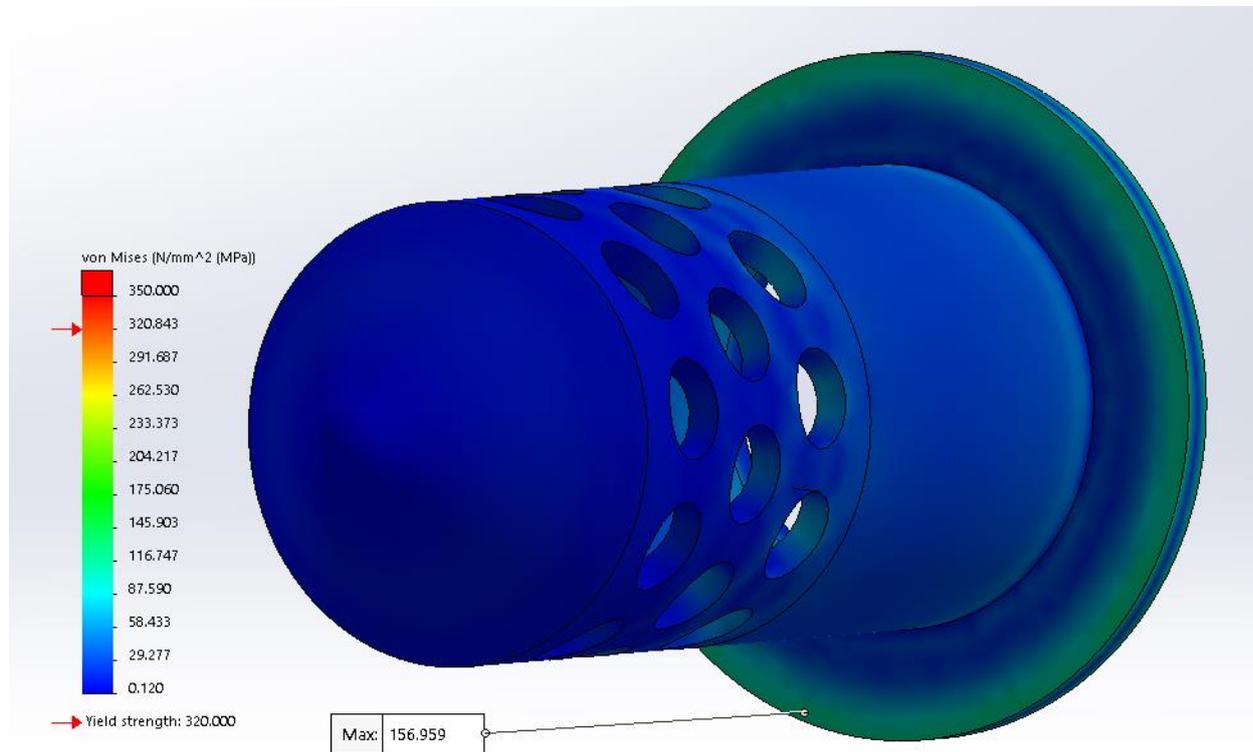


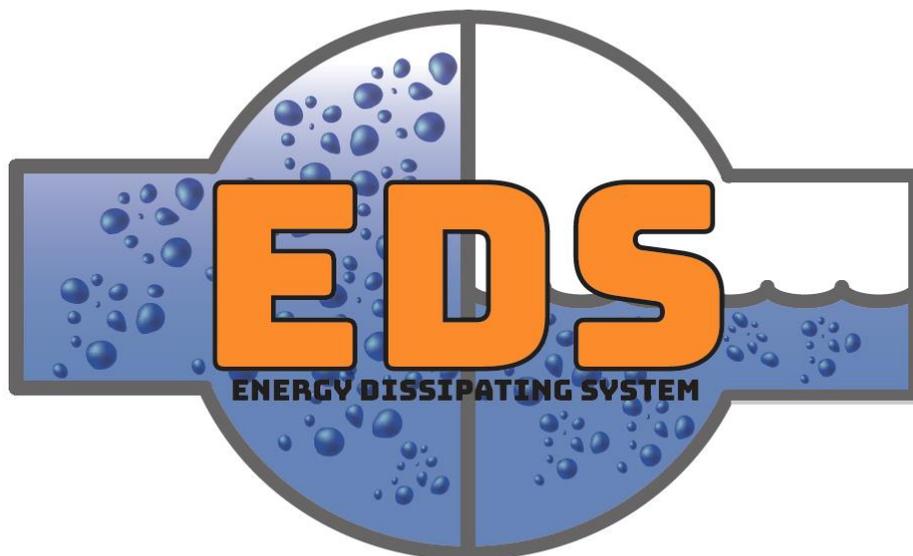
Figure 194: The highest stresses in the valve trim is where the trim is welded to the valve body. They are well within the limit at 157 MPa.

As the simulation shows the stresses are well within the limit of the chosen steel grade. In the material document, the trim will partially be constructed in 440C which has a very high yield strength of around 450 MPa (AZO Materials, 2012). The part can thus be optimized in terms of thickness to decrease the cost.

Multiconsult

Design of bypass valve Test report

22.05.2018



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Abstract

Background: In order to check if the system fulfills the system requirements, a set of tests has been made. The document contains a report of completed tests.

Method: The method used to evaluate the tests is either with FEM, flow simulations or theoretical calculations. The results are gathered from several analysis documents, where the final results are used. The result will either be PASS or FAIL.

Results: Tests that passed was T-1, T-2, T-3, T-3, and T-5. Tests who failed was T-6 and T-7.

Document history

Version	Date	Author	Description
0.00	07.05.18	OO	<ul style="list-style-type: none">• Created the document
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0.02	09.05.18	OO	<ul style="list-style-type: none">• T-1 and T-3 evaluated
0.03	10.05.18	OO	<ul style="list-style-type: none">• T-5 evaluated
0.04	14.05.18	LH, JS	<ul style="list-style-type: none">• T-8 Evaluated
0.05	17.05.18	MH	<ul style="list-style-type: none">• proofread
1.00	19.05.18	OO	<ul style="list-style-type: none">• Proofread• Changed reference setup

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1 Introduction

The development of the system is based on a set of requirements. These requirements serve as the foundation of the system, where each change or improvement in the design is done on the basis of them. To validate if the system fulfills the requirements, some tests have been created. These can be found in Test specification (*see Appendix B*). Each test must be linked to a requirement. In this document, the validation of the tests is done. At this point, the system is a parametric design thus the test will be performed theoretical. Most of the test results are gathered from simulations done in the construction phase. The related technical documents are the ones concerning the flow (*see Technical document: Flow optimization*) and FEM (*see Technical document: FEM*).

2 Test table

The table gives an overview of all the tests, with the related requirements, the date of when the test was evaluated, the person that evaluated the test and the test result. The report for each test is explained in the next chapter.

Test ID	Related RQ	Test date	Tested by	Result
T-1	RQ-1,RQ-2	09.05.18		PASS
T-2	RQ-3,RQ-6	08.05.18	OO	PASS
T-3	RQ-4	09.05.18	OO	PASS
T-4	RQ-5	10.05.18	OO	PASS
T-5	RQ-6	08.05.18	OO	PASS
T-6	RQ-7	08.05.18	OO	FAIL
T-7	RQ-10	14.05.18	LH	FAIL

Table 35: Overview of all the test and related information.

3 Test report

The chapter contains a report of all the tests given from the test specification document. Each test is evaluated in addition to a discussion sub-chapter. The test is labeled either with “Test pass” or “Test fail”.

3.1 T-1

“The system **MUST** operate with a flow rate up to $3\text{m}^3/\text{s}$ ”

The values used in evaluating the test is provided from the flow document (*see Technical document: Flow optimization*). The simulation is run with the given operational parameters where the objective is to obtain some values. These values will be used to calculate the volume flow in a fully open position. The values provided by the simulation is:

- **Mass flow:** 315.15 kg/s
- **Density:** 998 kg/m³

The volume flow rate is given in m³/s. By dividing density with the mass flow, the volume flow rate is obtained.

$$Q = \frac{998}{315.15} \left[\frac{\text{kg}/\text{m}^3}{\text{kg}/\text{s}} = \text{m}^3/\text{s} \right] = 3.17 \text{ m}^3/\text{s}$$

When calculating the values from the simulation, the group gets a volume flow rate equal 3.17m³/s. The test will then pass seeing as the volume flow has a satisfactorily value.

TEST PASS

3.1.1 Discussion

In a further development, the volume flow rate may be optimized in hence of getting it closer to 3 m³/s. Studying how the volume flow rate will change with different inlet pressure is also an opportunity. In an operational scenario, the pressure would not be constant but differ.

3.2 T-2

“Test flow rate on different settings numerous times and plot them in a graph.”

The test is simulated using fluent where the operational parameters are defined. By changing the position of the regulation from fully open to fully close and gathering the data the group were able to plot the graph illustrated below.

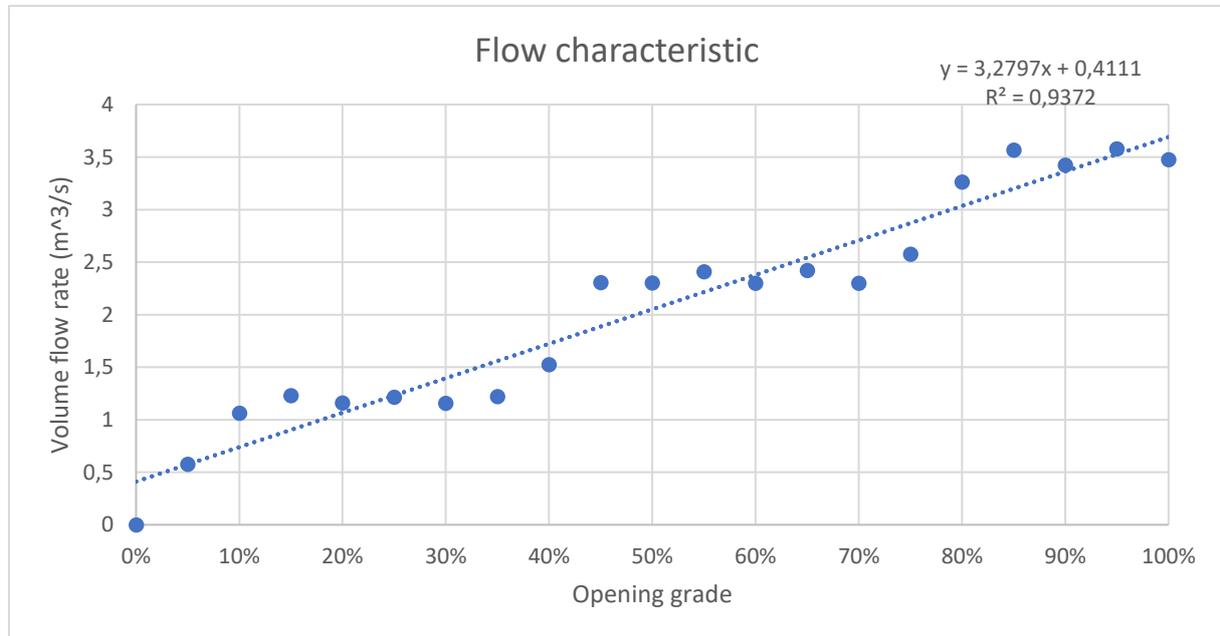


Figure 195: The graph is presenting the flow characteristic of the system. Each point demonstrates the volume flow rate at a specific opening grade.

The dots on the graph illustrates the different opening positions of the system where the x-axis gives the volume flow rate. The y-axis gives the opening position where 0% is fully closed, and 100% is fully open. The group tested out twenty different positions, which means twenty separate simulations. The points more or less present a linear flow characteristic without any substantial irregularities. With these result, the group can conclude that the test will pass.

TEST PASS

3.2.1 Discussion

When evaluating the flow characteristic in the concept selection, three types of characteristics were mentioned, quick-opening, linear and equal-percentage (Chapter 2.1 in Criterion analysis – flow characteristic). Of these three, the equal-percentage was the favored characteristic in applications where a more significant pressure drop occurred. In our case, the flow characteristic is not equal percentage which is not the optimal solution. Nevertheless, the system shows a predictable flow characteristic. In further optimizations, the flow characteristic may be changed more towards an equal-percentage flow characteristic.

3.3 T-3

“The system MUST manage cavitation satisfactorily.”

The simulation that will serve as the test result can be located in flow *document* (see *Technical document: Flow optimization*). The simulation is run in the fluent program where the operational parameters are applied. When evaluating the test, there are three acceptable outcomes; cavitation is not occurring, cavitation is occurring in a place where it does not do any damage and cavitation is occurring on a wear part. Underneath is a trajectory plot obtained from the flow simulation.

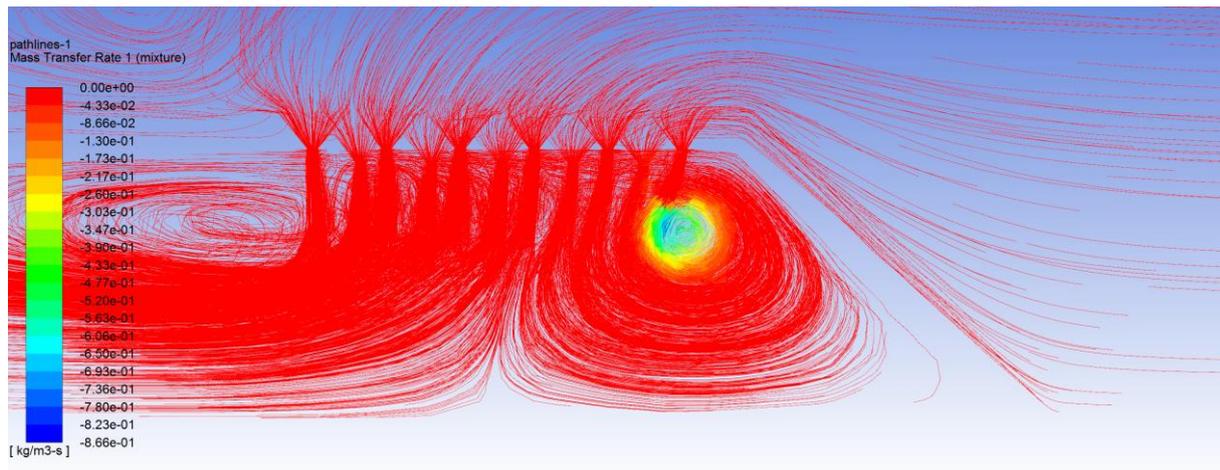


Figure 196: The plot is presenting the mass transfer rate in a cross-section of the system.

The trajectory plot is presenting the mass transfer rate in streamlines throughout the cavity in the model. Mass transfer rate can be explained as, quoted from “Flow optimization”-document, “It means the mass per unit of volume which is changing of phase. If it is positive, it means that the liquid is getting into vapor, and if it is negative it means the vapor is transforming into water, therefore, cavitation”. The red areas present the place in which there is no cavitation occurring. The green/blue section is where there is cavitation occurring. As we see the cavitation is forming in an area that is away from the wall thus, it fulfills one of the acceptable outcomes. The test will, therefore, pass because the cavitation is occurring in a place where it does not do any damage.

TEST PASS

3.3.1 Discussion

The simulation used to validate the test is run with a regulation step that correlates to a fully open position. There is not yet at this point any simulation where the cavitation is validated through a set of different regulations steps. It might occur cavitation if a hole is slightly open. The holes are also designed with a conical shape to force the cavitation away from the wall. In conversations with our stakeholder, a concern regarding the shape was raised. With such a shape the energy dissipation will decrease. In a further development, the optimization of the hole size and shape should be considered. This may result in a design that doesn't constrain the energy dissipation.

3.4 T-4

“Maximum velocity in the pipeline MUST not exceed 10 m/s.”

Values used for evaluating the test are provided from flow document (see *Technical document: Flow optimization*). Similar to the other flow simulation, the simulation is run with the given operational parameters. The acceptance criteria for the test is to get a velocity under 10 m/s in the downstream section of the system.

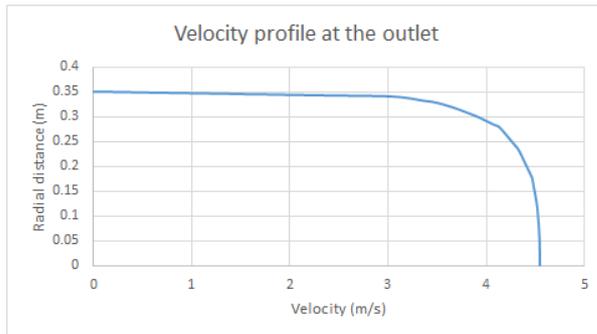


Figure 197: graph presenting the velocity at different radial distances

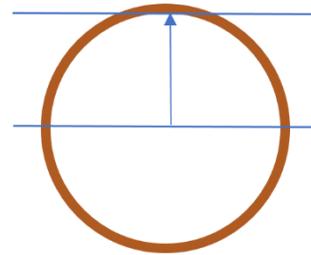


Figure 198: illustration of the radial distance. The center of the pipe is defined as origin.

Figure 197 presents the velocity profile at the outlet of the system where it shows the velocity through its radial distance from the center, 0m, to the inner wall, 0.35m (for illustration purposes look at Figure 198). The highest velocity occurring in the outlet profile is in the center where the velocity is 4.5 m/s. This value is under the maximum allowed velocity thus, the test will pass.

TEST PASS

3.4.1 Discussion

The requirement for maximum velocity is defined for the pipeline and not for the valve section where the holes/narrowed space are located. Having a high velocity through the holes is actually preferred. A general approach to dissipate energy is to force the water through multiple and narrow orifices which will result in higher velocity. The velocity through these orifices will then most likely be over 10 m/s.

3.5 T-5

“Metal parts that are in contact with the water will be tested using FEM. Forces equivalent to 300meter water column will be applied to expected areas.”

Simulation related to T-5 is located in FEM document(see *Technical document: FEM*). There is two simulation that will be used to evaluate the test. This simulation will be for the valve body and the valve trim. Both of the simulations are run with a pressure of 60 bar which correlates to 1,5 of PN40.

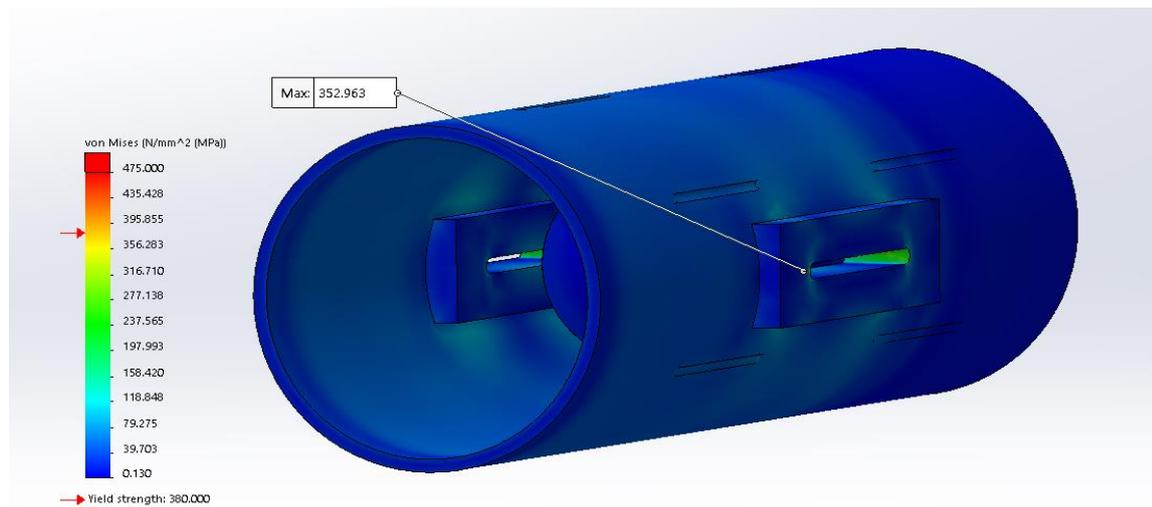


Figure 199: Finite element method simulation of the systems valve body. The plot presents the Von Mises stresses.

The first figure illustrates the Von Misses stress plotted at the valve body. The max stress is 352.9 MPa and can be located in the inside of the hole. The yield strength of the material for the valve body, P355, is 355Mpa. The result shows a value lower than the yield strength of the material in 1,5 of PN40. On the base of these facts, the valve body has acceptable strength.

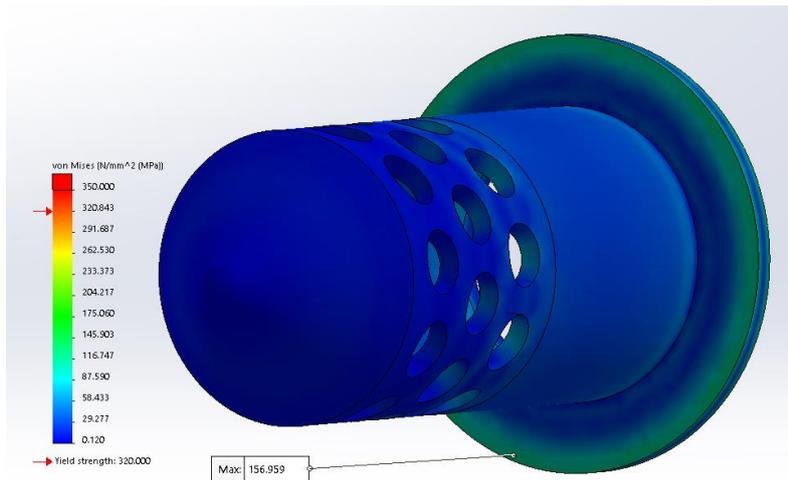


Figure 200: Finite element method simulation of the systems valve trim. The plot presents the Von Mises stresses.

The figure above illustrates the von Mises stress on the valve trim. The plot illustrates that the weakest point of the assembly is in outer side of the separating wall part. Nevertheless, the max stress is calculated to be 156,91 MPa and the max yield strength for the material is 320 MPa. With these results, the group can conclude that the valve trim part has a satisfactory mechanical strength.

TEST PASS

3.5.1 Discussion

The first FEM analyses displayed weaknesses in the holes of the valve body. As a measure, the group designed a reinforcement block to withstand the pressure. In a further development of the concept, it will be necessary to look at alternative solutions to reinforce the valve body rather than installing a massive block. The valve trim also has the opportunity to be optimized further considering the thickness.

3.6 T-6

“Calculate the production-cost of existing valves. Compare price to our system. The cost estimate of our system will be based on experience and SolidWorks.”

The acceptance criteria for the test was to get a system which was cheaper than 70% of existing solutions. The group has not gathered any information on prices of similar solutions and neither calculated the manufacturing cost of the system. On this basis, the test will not pass. RQ-7 will not be fulfilled in light of the fact that T-6 is the only test related to RQ-7.

TEST FAIL

3.6.1 Discussion

There are several reasons why this test did not pass. The first reason is the availability of information of costs concerning manufacturing on the internet is at its minimum. The problem was first encountered in the concept selection process where a criterion was production method. Initially, the group planned to get a very rough cost estimate of each concept. This was more difficult than expected. To a certain extent, the group was able to get some material prices, but these prices alone isn't a decent way to evaluate the cost. The cost concerning labor and processing will be a deceive factor, and these prices were more or less impossible to find. Another thing is that manufacturing costs are also dissimilar based on where in the world it is produced. The group had a plan to use the add-in on SolidWorks called "Costing". The add-in can make a cost estimate of a part, by defining production method and where it will be produced. The problem was that the add-in did not have the same materials as our system. In order to get the same material and manufacturing cost the group had to define the parameters. This lead back to the same problem. The group decided to focus on describing the production method more in detail then coming up with a price tag. If the concept where to be developed further, detailed evaluation of the production method would be a great help to figure out the cost. So by describing the production method, the group has set a base for cost evolution.

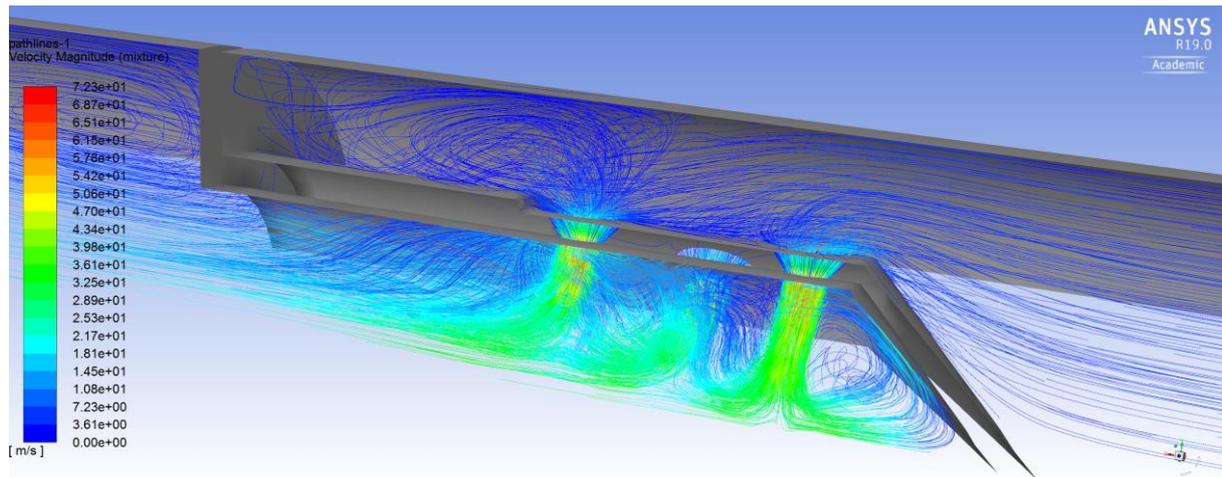


Figure 203: Velocity magnitude. As the fluid is forced through the holes, the velocity goes up. The flow is from left to right.

In Figure 201: Complete range of pressure at 25 bars of input pressure Figure 201 the complete range of pressures in the valve can be observed. The pressure before the orifices is as expected 25 bars. Through the orifices, the pressure drops due to the increase in velocity. In Figure 202 the pressure is scaled to highlight better the areas where it is below vapor pressure. This is acceptable as cavitation will occur in the transition to higher pressure, I.E., when it changes color from red to blue. Figure 203 shows the magnitude of the velocity. As the pressure falls, the velocity is going up.

3.7.2 PN64

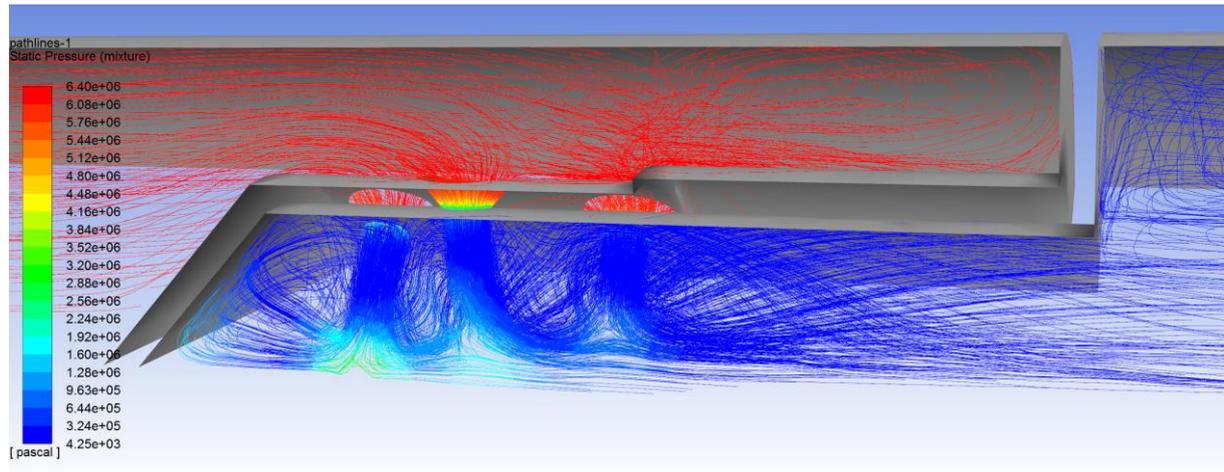


Figure 204: The complete range of pressure when the input is at 64 bars. The fluid flow is from right to left

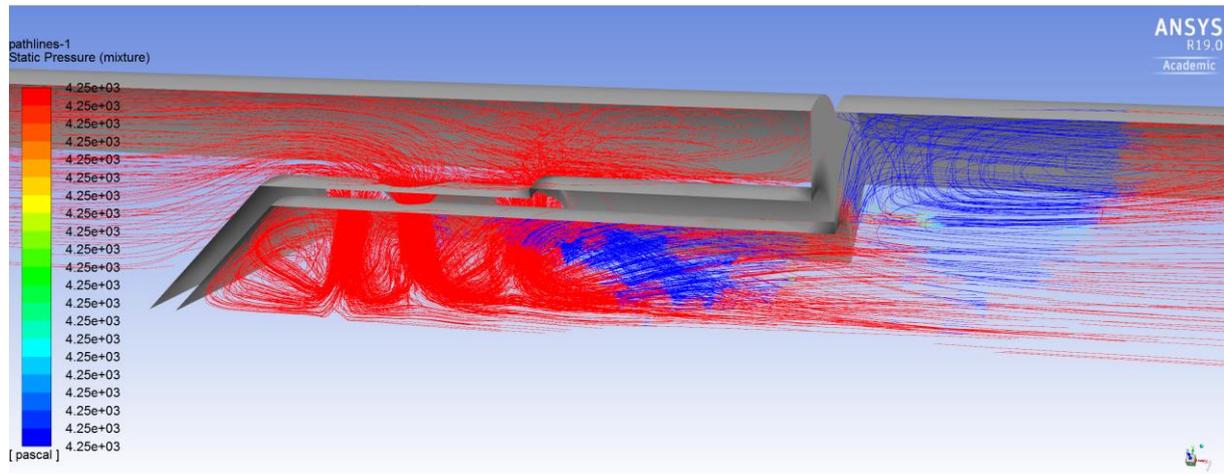


Figure 205: The pressure when it is scaled to highlight the areas that are below vapor pressure (blue). The fluid flow is from right to left.

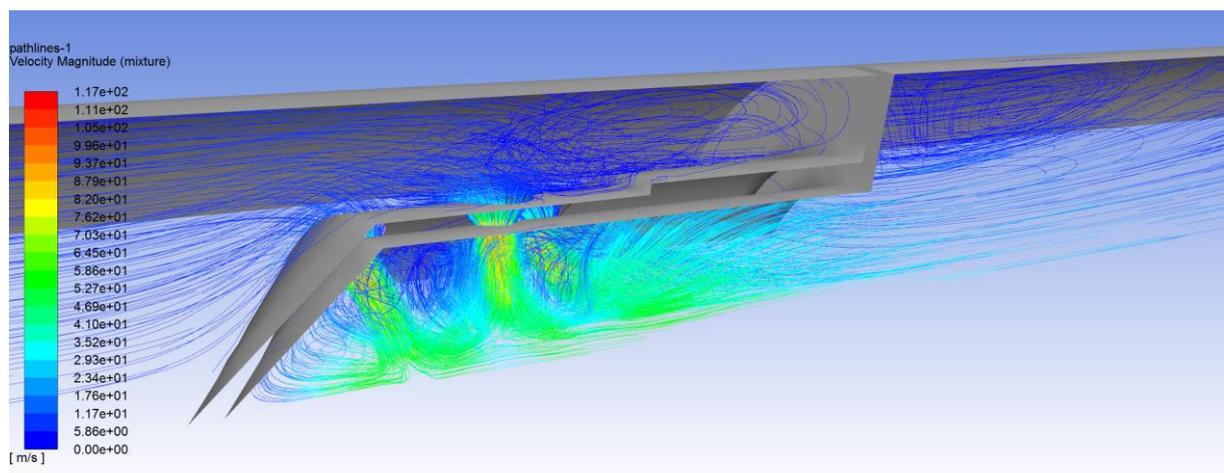


Figure 206: The velocity magnitude. The fluid flow is from right to left.

In Figure 204 the pressure plot can be viewed. The highest pressure is equal to the input at 64 bars. As previously explained in Chapter 3.7.1, the pressure drops as the velocity increases. Figure 205 shows the pressure when it is scaled so that everything that is above the vapor pressure is in red, and at or below the vapor pressure is in blue. This is the region where vapor is formed in the fluid, and at the region where the pressure rises above the vapor pressure cavitation will occur. The blue region is large and it is clear that cavitation will occur at PN64

3.7.3 Discussion

The simulation done in fluent shows that it is no problem with scaling the pressure down and keeping the same design, but if the pressure is scaled up serious cavitation will occur. This makes sense as the valve is optimized in terms of cost efficiency to deal with PN40 and not pressure classes above. If the design also where to be scaled to a degree, the group is confident that the same advantageous flow characteristics as PN40 will occur. But as only half the test passed, it will still be considered a fail.

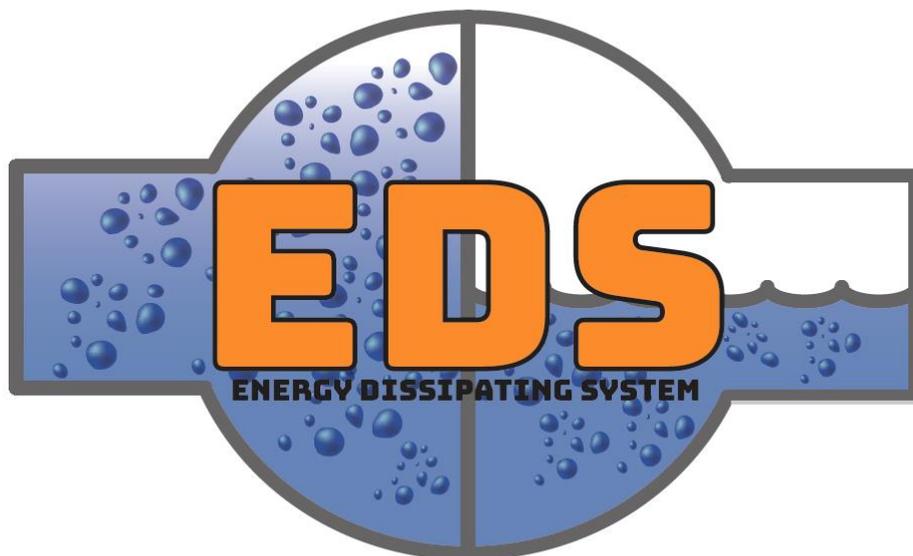
TEST FAIL



Multiconsult

Design of bypass valve Project conclusion

22.05.2018



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Document history

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0.01	21.05.18	JS	<ul style="list-style-type: none">• Added more
1.00	21.05.18	LH	<ul style="list-style-type: none">• Restructured and removed some irrelevant parts.

Conclusion

The Energy Dissipating System (EDS) is theoretically viable as an alternative to the current bypass systems. FEM and flow simulations described in the *Technical document: FEM and Technical document: Flow optimization* shows that EDS fulfills the flow and material .

Throughout the design process, using as many standard components as possible has been one of the primary objectives to minimize the cost. The parts are also designed to use alternative production methods such as plate rolling and cutting, as described in the *Technical document: Assembly*.

EDS fulfills most of the requirements, as shown in the *Test Report*. However, there are two requirements unfulfilled. These requirements are the estimation of the production cost and the scalability of the product. In relation to the production cost, the group has had difficulties finding specific numbers for the cost. As a remedy, the group made an analysis providing a specification of the production method considered for each part, making it easier for a further manufacturing cost estimation. Concerning the scalability, simplified scalability tests show that there is no problem for EDS to be used in a smaller power plant with a lower input pressure. The problem arises when scaling the pressure above PN40, which will require design changes to the diameter and thickness of the material.

EDS needs more optimization to be a competitive solution in the valve industry. Service and maintenance for the valve need to be analyzed, and a service hatch added. A thorough cost estimate and optimization need to be conducted. With some changes to the design in terms of service and cost-efficiency, the EDS can be a viable product to compete with the bypass valves in the market today.

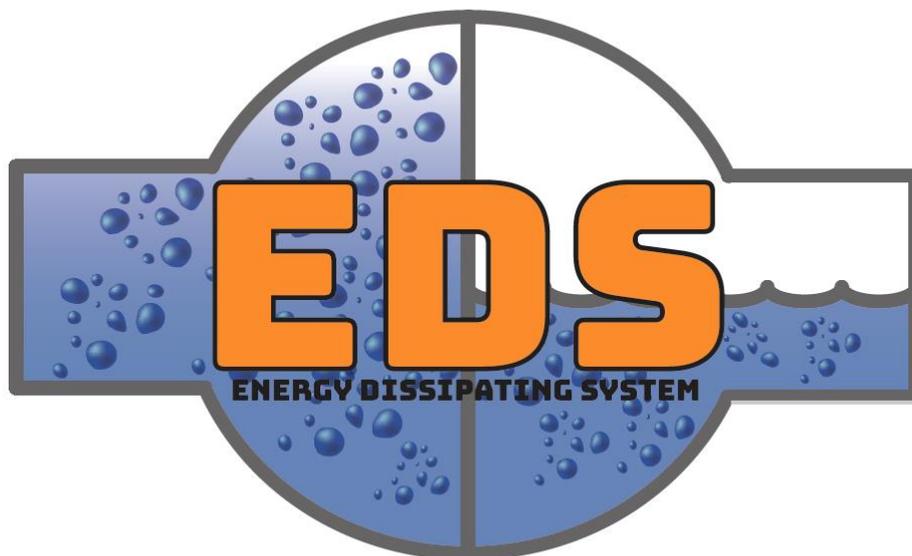


Multiconsult

Design of bypass valve

Project evaluation

22.05.2018



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0.01	15.05.18	OO	<ul style="list-style-type: none"> Structured the document Made bulletpoints for every chapter
0.03	15.05.18	LH	<ul style="list-style-type: none"> Made draft evaluations in the technical chapter
0.04	15.05.18	OO	<p>Written evaluations for:</p> <ul style="list-style-type: none"> Introduction for project evaluation Project process Iteration plan Activity plan Written parts of requirements, tests. Flow simulation Parts of Finite element method Rewritten Computer aided design
0.05	18.05.18	LH	<ul style="list-style-type: none"> Rewrote most of the chapters Added more in-depth evaluations in chapter 2
1.00	20.05.18	JS, MH	<ul style="list-style-type: none"> Proofread and correct

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1 Introduction

The project evaluation is an important step to do. Here the group will assess the work that has been done in terms of productivity, project related choices, time usage and the results. The nature of the iterative model that has been applied in the project has enabled the opportunity to evaluate as the project developed. An aspect that has not been evaluated in depth yet is the design results. The group considers it important to explain why some aspects and goals was more important than others were, especially because the project has a time constraint and that not all the goals were fulfilled.

2 Evaluation of the project process

During the inception-phase the project plan was created. The plan is a tool to guide the group through the project. The project plan describes guidelines for the project model, responsibility areas, meetings, activities, etc. In this chapter some of these tools are evaluated. What worked and what did not?

2.1 Project model

The project model is one of the tools that indisputably have had the most significant effect on the project execution. The project model has helped the group to get a high-level overview of the project life cycle. At the start of the project, there was no clear route for the direction of the project. All we had were some stakeholder requirements within a system that we had little to none practical knowledge in. The project model enabled the group to split the project into four phases where each phase consisted of a specific set of workflows (activities). This enabled the group to plan more in-depth although the system itself were not wholly understood. The project model used was a slight variation of the Unified Process (UP), hereby referred to as “our model”. The model was an iterative project model which worked very well in our case. The iterative part of the model is discussed and evaluated in Chapter 2.2. Our model has one key difference from UP, the use of use-cases. Use-cases help to understand the system and establish system requirements and make a “frame” for the project. The group decided to not apply use-cases since use-cases aren’t relevant for this particular system. Looking at it in hindsight, it might have been valuable in some aspects. During the process some misunderstandings has occurred regarding the requirements that might could be avoided with the implementation of use-cases. For example, RQ-1: *“The system MUST operate under the pressure of 100- to 300-meter water column”* could have been more specific in terms of the guidelines the Norwegian power-plants have to operate within. For valves and pipelines there are pressure classes, but this was established much later than optimal. In cooperation with Multiconsult, pressure class PN40 was chosen for the design which should have been the requirement.

2.2 Iteration plan

As mentioned in the last chapter, the use of iterations is highly related to our model. In the inception phase, “planning phase”, each iteration was explained in terms of high-level objectives. The iterations are explained in depth in the iteration document (*see Appendix D*). When evaluating the iteration plan to the actual execution, the group see that it more or less correlates. In addition of the iteration description in the project plan (*see Project Plan*) the iteration document contains a more detailed description of the objectives. There were some changes in the iteration plan, not in the iteration objectives itself but the duration of them. Because of the use of the iterative model, the changes were effortless to implement and the impact on the process was minimum. One of the noticeable changes to the iterations plan is the C2 iteration which is a part of the concept development. The plan was to decide the final concept before the second presentation, but this task required longer time than expected. Instead of rushing a decision, the group decided to extend the iteration with one week. Another change is the C3 iteration which briefly described is the designing process of the selected concept. What the group detected here was that the objectives were too high-level and vague. By splitting the iteration into two “sub-iterations”, the objectives became clearer.

2.3 Activity plan

The activity plan (*see Project Plan*) gives an overview of when and what kind of activity that was done, and the required time to do it. The plan was intended to be a tool to help estimate the work amount in each iteration as well as the activities. In the first iteration this practice was used, but through the process it faded a bit. One reason is that some of the activities were discarded. In the planning phase, we had to assume some activities that might come later in the project. It turned out that some were not related to the project. Because of how the setup of the activity plan was, changes were not simple to make. Looking back, it would have helped to make the activity plan simpler and not so specific to easier implement changes. The activity plan also had a second purpose of logging hours to compare the estimated hours in each activity to the actual hours worked.

Workflow & activities		Total est. time	Total reg. time
1. Project administration			
	1.1 Proofreading documents	68	229,5
	1.2 Web page	18	18
	1.3 Meeting minutes	41	81
	1.4 Presentations	92	99,5
	1.5 Project plan	102	134
	1.5 Project model	17	30
	1.6 Gant diagram & time schedule	20	27,5
	1.7 Activity plan	29	37
			0
2. Requirements			
	2.1 Create requirement specification doc.	8	8
	2.2 Requirement specification	67	25
	2.3 Updating requirement doc	31	12
3. Research		0	
	3.1 Research	240	122
	3.2 Training in new software	145	101,5
	3.3 Production methods	80	54
	3.4 Research papers	75	12
4. Test			
	4.1 Test analysis	90	14
	4.2 Test specification	65	44
	4.3 Carry out tests	50	0
	4.4 Test report	44	42,5
5. Design & Analysis			
	5.1 Cad modelling	170	175
	5.2 Flow analysis	170	260
	5.3 Finite element method analysis	140	43
	5.4 System control analysis	50	0
	5.5 Risk analysis	55	45
	5.6 Cost/benefit report	100	0
	5.7 Concept development	155	172
	5.8 Documenting concepts	0	74,5
	5.9 Concept analysis	120	117
	5.10 Technical documents	0	259
Total Hours:		2242	2237

Table 36: Activity plan with estimated hours vs total registered hours

Table 36 shows that most of the activities has roughly the same estimated time and registered time. It should be noted that the total registered time is expected to rise due to

the fact that we are not done with the project yet. Expected time left is around 100-150 hours. As mentioned some of the activities were not done like 4.10 test analysis, 5.4 system control analysis and 5.6 cost/benefit report. This is either because the task was not applicable anymore or that the time was spent elsewhere. Some activities were not estimated, like 5.9: Documenting concepts and 5.10: Technical documents.

2.4 Meetings

Every week, two external meetings was held. One with the internal supervisor, and one with Multiconsult. The internal supervisor meetings was held on Mondays at the group room, and was used as an extra review of the plan for the next week and assessing the work that was done the previous week. The meeting with Multiconsult was held on Fridays over skype, it was used to review the more technical parts of the work. A “face-to-face” meeting is always preferred, but as Multiconsult offices are in Drammen having a skype meeting meant less time for travel for the group.

At Mondays before the internal supervisor meeting, the group discussed the plan for the next week. The plan was developed by looking at the iteration plan and assessing the work done the previous week. Every day the group members also met to discuss the most important tasks for that specific day.

The meetings the group has had during the project period has gone well. By having short group meetings every day enabled us to better have the project goal in mind and working efficient towards this goal.

3 Technical evaluation

In this chapter the evaluation of the project concerning the technical work is evaluated. Does the system have the intended requirements? Which tools are used and what is the experience?

3.1 Requirements –and test specifications

Multiconsult provided the stakeholder requirements that made a rough outline of the design. Here it was specified certain design limitations and parameters that the valve had to abide by. The stakeholder requirements were specified and transformed into system requirements. Requirements with a dimensional limitation were used to define simulation parameters or finding the desired values for the simulation. Others were used in the concept development by evaluating operational solutions. Most of the requirements has actively been used through the development of the system. When testing the requirements, some requirements are not fulfilled. These requirements are relating to the scalability and cost. Making a competitive solution regarding the cost was one of the conditions for the system. Evaluating cost and estimating cost concerning the production of the system was a tougher task than expected. The group was not able to gather credible information concerning the manufacturing cost for different production methods. The focus was, therefore, changed to emphasize more on describing the production method. A respectable evaluation of the production method can serve as a foundation for evaluating the cost in further development. The group has been able to evaluate the scalability in some cases. Selection of some components has been done on the basis that it should be able to scale the system up. Some simple simulation with the PN25 and PN64 has also been done. Nevertheless, the group should have focused even more on those two requirements.

3.2 Flow simulation

Flow simulating programs has been a tool to help the group to understand how the water is flowing through the system. There are two programs that has been used, Flow simulation on SolidWorks and Fluent on ANSYS. For most of the group both these programs were new, and the first part of the construction phase went to learning flow simulation in SolidWorks. SolidWorks flow simulation required less time to setup and run simulations compared to Fluent. Seeing as there was ten concepts to simulate, SolidWorks was used in the concept selection process. Also, the concepts were in a rough state. A detailed simulation would then have been unnecessary. ANSYS fluent was later used in the optimization of the selected concept. At this point, there was just one concept which meant that there was possible to set up a more complex simulation. With fluent, the group was able to optimize the concept in ways that might not have been possible with SolidWorks flow simulation. In retrospect, the whole group should have learned Fluent instead to have a common understanding of the simulation setup. Human errors can occur in the setup of simulations and have a second person to evaluate is of great use. It should be said that it requires more time to learn Fluent, but in hindsight it might have been a better solution.

3.3 Finite element method

Finite element method analysis was performed in the construction phase, and all the group members have knowledge in FEM. This made it easier to validate the results with the rest of the group and make sure that the simulation parameters were correct. The results were implemented in the design as the simulations were carried out to make the design withstand the operating pressure.

One of the challenges that were solved with the use of FEM were the installation of the reinforcement block. The group realized the slots in the valve body was a weak spot in the model. To make the valve body strong enough a massive block was installed. With the practice of FEM, the reinforcement block was optimized to be as small as possible but still withstand the operational environment.

3.4 Computer aided design (CAD)

To create concepts and ideas, the group applied the use of computer aided design programs. These programs gave the group the possibility to draw 3D models with the predetermined dimensions. Models created in these software were later used in Flow and FEM simulations. Catia and SolidWorks were the two CAD programs that were used. The programs are both developed by the same company, Dassault Systems, so that the models could be modified on both programs. Even though the programs had the same owner there was some problems transferring the files, but it was tolerable. In the later stages, SolidWorks became the main program for design development. Complete parametric design of the system is delivered to our Stakeholder. At this point, the parametric design fulfills most of the requirements set by our stakeholder, but there is still optimization to be done. Missing elements in the design is the implementation of serviceability and assembly of the system. At this point, the assembly of the system will be a little bit complicated. Serviceability regarding change of wear parts and implantation of a service hatch is still missing. This was not a system requirement, so the designer itself is not the one to blame. Serviceability was a stakeholder requirement and in prospect, it should also have been applied as a system requirement.

4 Time consumption

In this chapter, the time consumption will be evaluated. In the inception phase, the group estimated how many hours that would be spent in each phase, and in each activity. How each group member has worked throughout the project will also be evaluated.

4.1 Estimated time versus registered time

When estimating the hours needed for the project the group looked at the subject itself. The bachelor thesis is a 20 credits subject, and according to ECTS this will require 500-600 hours of work. For more information about the estimation look at the project plan (*see Project Plan*). The activity plan was also based on this information.

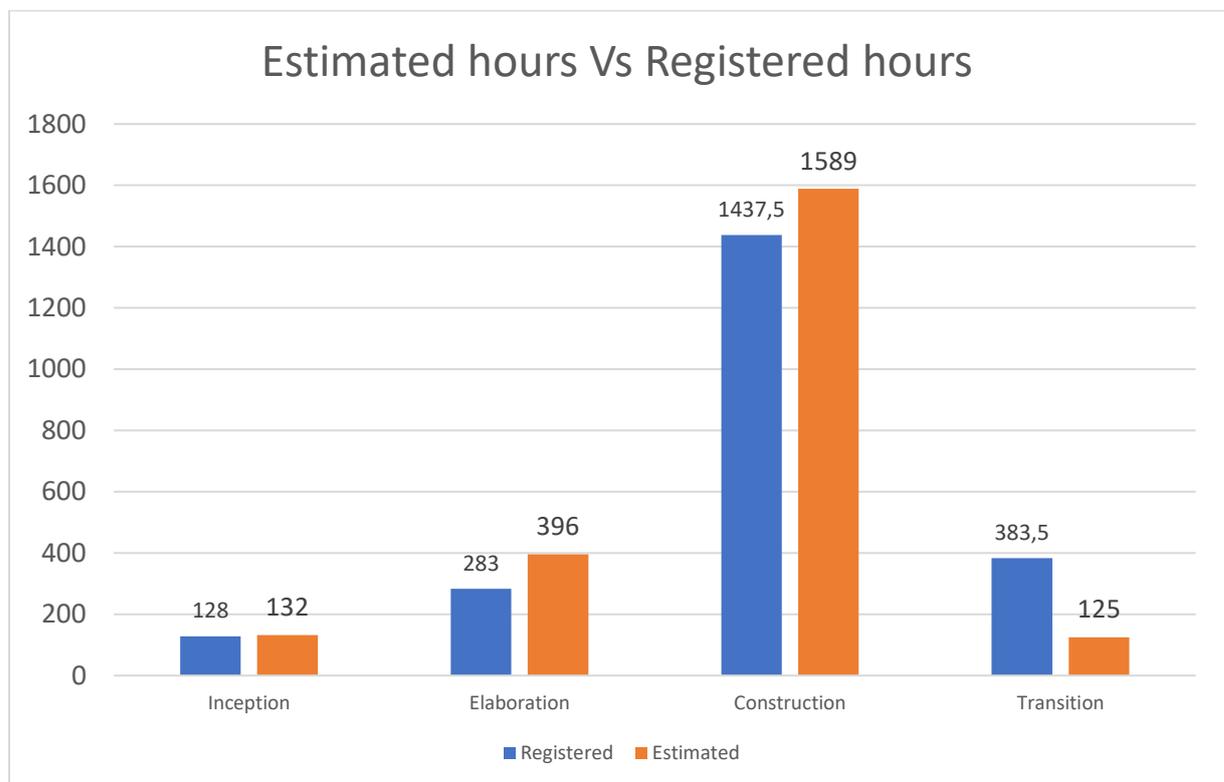


Figure 207: Estimated hours as the orange columns vs registered time as the blue columns

The four different phases in the project model will be used to evaluate the time consumption through the project process. Figure 1 compares the registered hours with the estimated hours. The blue column is the registered hours and the orange post is the estimated hours. In the inception phase, we see that the estimated compared with the registered is more or less equal. In the elaboration phase, the group has worked 100 hours less than estimated. This can probably be the reason why some requirements were not completely understood correctly until the middle of the project. In the next phase, construction, there is a difference of nearly 150 hours. With 150 hours more with design, a service hatch or a more maintainable design could have been completed. The noticeable difference in the graph is the transition phase, where the group has worked three times more than estimated.

Due to the fact that the registered hours in construction were less than estimated, there are results in a design that could have been optimized more. Good documentation is a large part of the bachelor thesis, which we have focused on. This explains the large delta in estimated vs registered hours in the transition phase. Even though there are some difference, the total estimation is close to the registered, seeing as this is the first time the group has planned a project of this size.

4.2 Time distribution in the group

To archive a respectable result there is essential that all group members participate in the process. Inequitable distribution can affect the groups dynamic as well as motivation, resulting in an undesirable project execution.

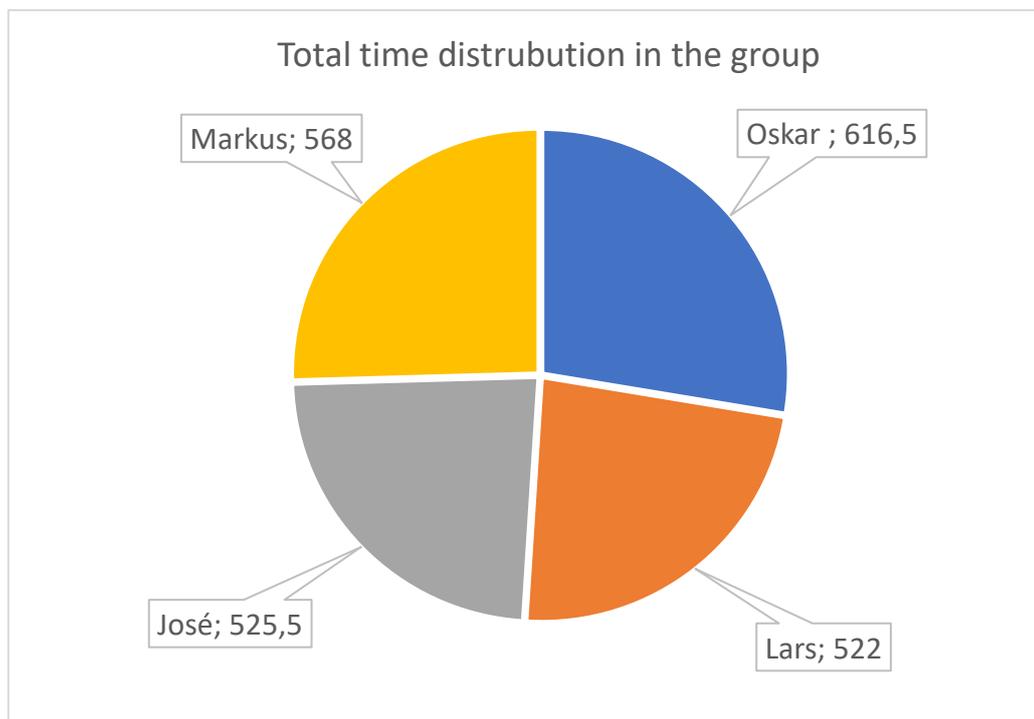


Figure 208: Hours worked per person

Figure 2 illustrates the total time distribution in the group in a sector diagram. As seen from the figure, there are some differences in the amount of work. But when seeing the bigger picture, the difference is minimal. The graph show that each and one have contributed approximately $\frac{1}{4}$ of the total, which is the ideal distribution.

4.3 Distribution of hours throughout the project per member

As mentioned in the last subchapter, having all the group members participating in the project is essential. But it is also equally important that the contribution is distributed throughout the process. If a member crunch time in the last weeks, the result may not be optimal.

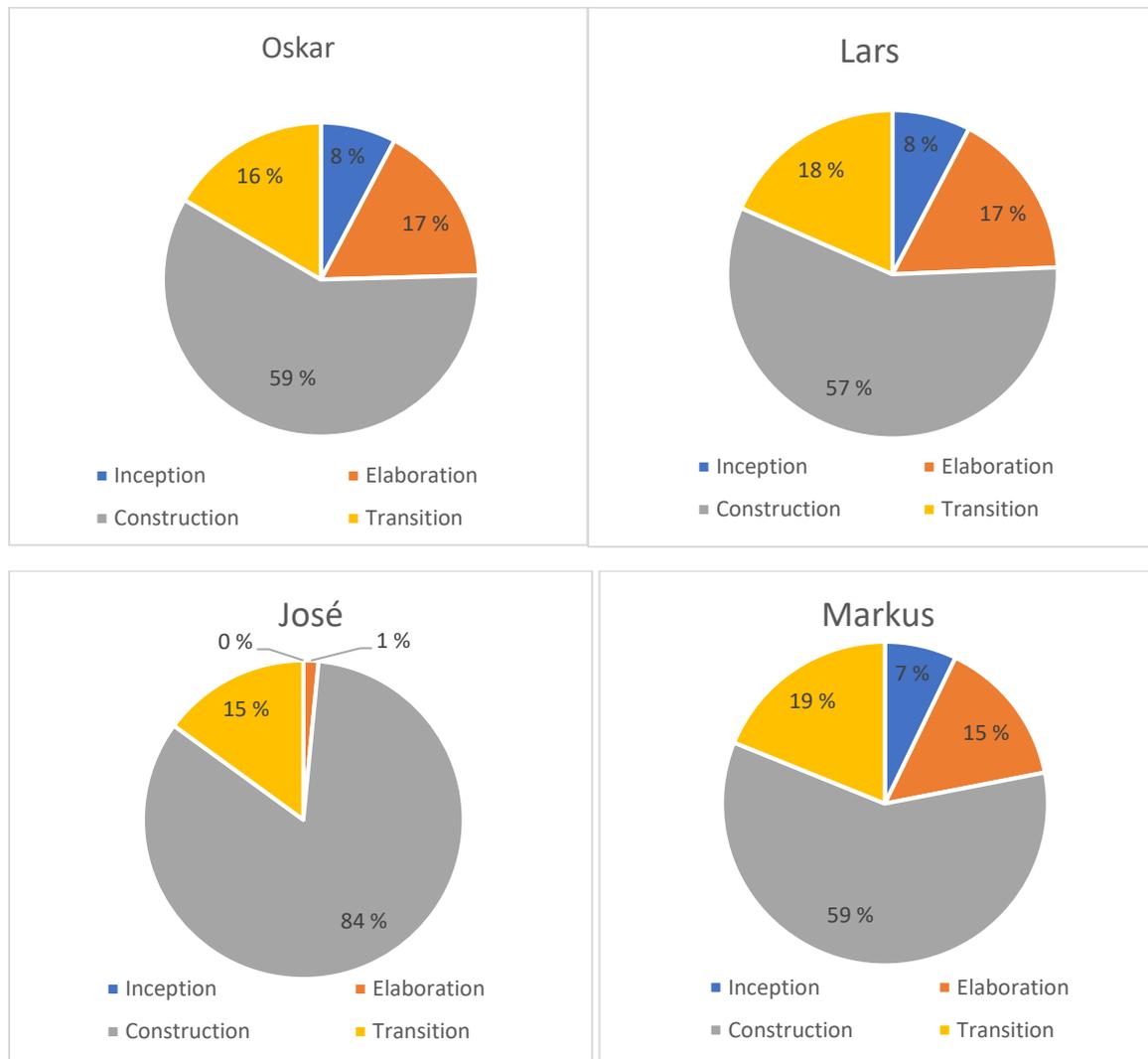


Figure 209: Pie chart showing each members distribution of hours throughout the four phases

Figure 3 presents the total hours of work for each group member distributed over the four phases. Three of the sector diagrams look similar which suggest that the work effort through the phases has been more or less equal. There is one noticeable difference in the sector diagram. One of the group members did not arrive until the 1. February because there were no available places to stay until that date. The plan was to communicate via Skype in this period. The communication in this period could have been better.

5 Risk evaluation

There has been a lot of risks to this project, both concerning the system itself and the group (see Appendix C). As the risks for this project were listed during the Elaboration phase, E1, it would be nearly impossible to predict every single risk to the project. Some risks were therefore added later in the project, as the group anticipated them or as they were happening.

Throughout the project it is helpful to evaluate the risks, that way they can be prevented in the future. This will not only help the progress of the project but will also give each group member valuable experience and insight within risk assessment.

5.1 Evaluation chart

When it comes to the design of the system, most of the risks have been avoided or handled properly. This is primarily due to the fact that most of the system risks originate from requirements set by Multiconsult. That being said, the risk analysis has certainly helped in the progress of the designing phase. By exploiting the work, the group has already done, possible disasters were avoided.

Disasters regarding the group have also been avoided. By having thought of the risks before they occurred, the group were prepared to handle most situations.

All in all, the risk analysis has been a helpful tool throughout the project. With a little effort in the beginning of the project, the group was able to foresee multiple risks, and therefore avoiding or handling them. After the initial making of the analysis, very little work has been done to it, even though the group has used it at multiple occasions. It has simply been used as the tool that it is, and the group has been able to reap the benefits of having it.

Risk ID	Risk evaluation
RI-1.01	<p>Multiconsult backing out of the project.</p> <p>Multiconsult has become more and more involved in the project.</p>
RI-1.02	<p>Group member being sick over an extended period.</p> <p>No members have been sick, but some has been away for personal reasons.</p>
RI-1.03	<p>Loss of documents.</p> <p>Onedrive and local hard drives has been used to save documents.</p>
RI-1.04	<p>Language-barrier leading to misunderstandings.</p> <p>The language-barrier has not been an issue, as all members are virtually on the same level of English-knowledge.</p>

RI-1.05	<p>Internal deadlines not being met.</p> <p>Some internal deadlines were postponed or not met; the group then changed the project plan to accommodate for this.</p>
RI-1.06	<p>External deadlines not being met.</p> <p>All external deadlines have been met.</p>
RI-1.07	<p>Scope of assignment is bigger than expected.</p> <p>The project has been manageable, but due to inexperience in the field, the design has not been fully optimized.</p>
RI-1.08	<p>Low motivation in group.</p> <p>At times, the motivation in the group was low. Mostly related to analyses and documentation.</p>
RI-1.09	<p>Don't get access to necessary equipment for testing etc. in the workshops.</p> <p>Having some problems with software licenses. Biggest problem is not having access to various standards.</p>
RI-1.10	<p>Disagreement within the group, or towards external supervisors.</p> <p>These situations have for the most part been avoided as the group and supervisors has a common understanding of most subjects.</p>
RI-1.11	<p>Group members deliver different quality of work.</p> <p>Has occurred on multiple occasions but has not been a problem. The group members have helped each other to produce good documentation.</p>
RI-1.12	<p>Difference in amount of work put down.</p> <p>Some differences in time put into the project by each member has occurred. These differences are for the most part justifiable, so no real reason for concern.</p>
RI-2.01	<p>The system is not able to hold a water-column of 100 to 300 meter.</p> <p>Design changes were made so that the system would withstand the water column.</p>

RI-2.02	<p>The system can't withstand a flowrate up to $3 \text{ m}^3/\text{s}$.</p> <p>Design changes were made to allow for a flowrate of $3 \text{ m}^3/\text{s}$. system can handle it without problem</p>
RI-2.03	<p>Can't control the system flow rate.</p> <p>Flow rate is controllable. Close to linear flow characteristics. Room for improvement.</p>
RI-2.04	<p>The system isn't resistant to cavitation.</p> <p>The system is resistant to cavitation for the most part. Some cavitation might still occur in controlled places.</p>
RI-2.05	<p>The areas where cavitation occur aren't changeable.</p> <p>Areas affected by cavitation is changeable.</p>
RI-2.06	<p>Velocity at the exit of the system exceeds 10 m/s.</p> <p>Change 2.06. Talking about velocity in water filled pipes, not at exit. This limit is not exceeded.</p>
RI-2.07	<p>The system isn't satisfactory when it comes to mechanical strength.</p> <p>The mechanical strength of the system is suitable for its purpose, but the design could be optimized to handle the forces better.</p>
RI-2.08	<p>The system is not in compliance with the guidelines from NVE.</p> <p>Guidelines from NVE has mostly been follow. NVE uses NS-EN which the group do not have access to, therefore, we had to use some open source American standards.</p>
RI-2.09	<p>The system does not pass basic safety standards.</p> <p>No immediate dangers produced by the system. Open gear solutions = should be covered.</p>
RI-2.10	<p>The system is not scalable.</p> <p>The system can be scaled down without problem. Scaling it up will require design changes or further reinforcements.</p>

RI-2.13	<p>The system costs more to produce than existing systems.</p> <p>The group do not have any good way to measure the cost at this point. Estimation of cost is, therefore, at this time just assumptions. But from the groups point of view the system will either cost the same or more than existing solutions.</p>
RI-2.14	<p>The system can't be controlled from a remote location.</p> <p>The system has been equipped with actuators, making it possible to control from a remote location.</p>
RI-2.15	<p>Analyses are inaccurate.</p> <p>After multiple concerns from Multiconsult, there are still some uncertainties regarding some of the analyses.</p>
RI-2.16	<p>Poor design choices.</p> <p>There have certainly been some poor design choices. But because the group choose to use an incremental approach, these choices has been altered.</p>

6 Personal evaluations

6.1 Oskar Oulie

Looking back at the project, I can safely say that I'm mostly satisfied with both the result and the process. I had the role of being the group leader which at some points has been challenging, but overall the learning outcome from the practice has been significant. Challenges that were faced in terms of the project process was to figure out all the steps necessary for an iteration. But also putting the objectives in the right order and allocate an appropriate timeframe to do it. throughout the process the planning skills have improved and setting up a doable iteration became easier. Being able to plan and execute a project of this size will be an experience I will take with me in later studies.

The project itself, with the development of bypass valve, has also had its ups and downs. The project enables the group to innovate, but at the same time, it requires a lot from us. Trying to create an improved, cheaper and overall better solutions in a field where we have a lack of knowledge caused some headaches. On the other hand, it enabled us to study and learn new knowledge and also extend some. For example, with fluid mechanics where most of the group members just had an intro course, we had to opportunity the extend the knowledge. Learning to set up and simulate fluid flow has been a great experience, and I hope I will get the chance to use it in a later possible career.

As a part of the project group, we have had a foreign exchange student. This has led to the entire working environment being in English. Initial, it scared me a little, but now all I can say is that I'm grateful for having such an opportunity. It may have made it slightly harder to write in a good technical and academic way, but ultimately the project has been about facing challenges and overcome them which I feel we have done together as a group.

6.2 José Mato Sanz

Being an exchange student has supposed additional difficulties for me and for the rest of the group. Not only arriving one month later due to the different academic calendars of the Universities, but also the difference in language, knowledge, culture and working procedure. At the beginning of the project, it led to a less efficient group due to a slower communication and understanding. Some misunderstandings resulted in wasted hours of work in several cases. However, due to the effort applied by all the group members for working collaboratively and not as separated individuals, we became a well-organized and motivated group. I am very proud of the overall performance.

Throughout all the project life cycle, the group has faced certain difficulties, some of them not related with the project. The group had few or no knowledge at all in several technical areas, resulting in wasted time due to misunderstandings and a lot of time apply in learning. The final product is not a complete solution for the problem, but, from my prospective, it is a good product with a lot of potential, which does not require big changes to become a competitive solution. Probably, the group could have performed better, however, from every single mistake we all have learned a lot and we have work hard to acquire the best final product.

To conclude, it has been a great experience. I have applied the knowledge acquire during my degree in a complete engineering project and learnt many new things. Specially, applying the systems engineering approach, something inexistent in my University, has shown me a new kind of engineering, which for sure will be very valuable in my professional future.

6.3 Markus Hjellseth

To start off, I think the project is successful even though the optimization of the system is not complete. To think that the group has come up with a system of this caliber, quality and potential makes me proud.

When we received the project description, I immediately became excited. I thought the project sounded interesting where we would create a better alternative to existing solutions. Being able to compare our competence to the rest of the industry only increased my excitement. That being said, I knew it was going to be hard. The industry-leaders spend millions of dollars to develop systems like this, and to think that we, a small group of students are going to out-do them is rather optimistic.

Seeing as we are a small bachelor group, each group member had to take on several responsibilities. My main responsibilities were being the Designer/CAD-manager of the system, as well as being the Risk manager for the project. Being the Designer of the project was by far the biggest responsibility for me personally. I felt that it fitting that I got the responsibility as I already hold a bachelor degree in Design. To design the system I implemented the results given by various analyses into the concept. This was all sculpted in the software SolidWorks. Through the role as the designer I have worked on, or been in contact with, all parts of the project. I especially liked this part as it has allowed me to work creatively.

My second role has been the Risk manager. This was really only work in the beginning of the project when the risk analysis were created. After which it has been smooth sailing and reaping the benefits of heaving done a good risk analysis on beforehand. This responsibility has given me valuable insight in all the things that can go wrong in a project, and only reinforced my belief in that it is better to be prepared for problems than handling them as they come.

When it comes to the group I am very happy with how we have performed throughout the project. The challenges we met were resolved in a professional manner, we acted professionally towards external parties and most of all everyone respected each other as well as the process. Even though we had some ups and downs through the project, every group member was willing to put in the work needed to complete the project.

6.4 Lars Bergh Røste Hvidsten

My role in the project was Requirement manager and FEM manager. My responsibility was to create the requirement specification and define the system requirements. I also had a responsibility within finite element analysis on the final concept, to conduct it and implement the changes that had to be made to the design. I have also been responsible for creating the web page since I was the only group member with experience within coding. I had to learn basic HTML to do this, it took some time but I am quite pleased with the result.

I would have liked to have a larger responsibility within CAD and design, but seeing that all the members of the group was mechanical engineers this task was given to somebody else. During the project time, I also had to take a week of due to personal reasons.

It has been very exciting and fun to see the progress that we have made from the start. We got a lot of freedom in how the design should be from Multiconsult and I think for me, the concept development has been the most fun part. I think the group worked very well together, everybody did their part and helped each other. I have gained a lot of experience in project work and planning. The most challenging part for me was to solve the problems that was found during the FEM analysis regarding the design and finding the right material choice based on these analyses.

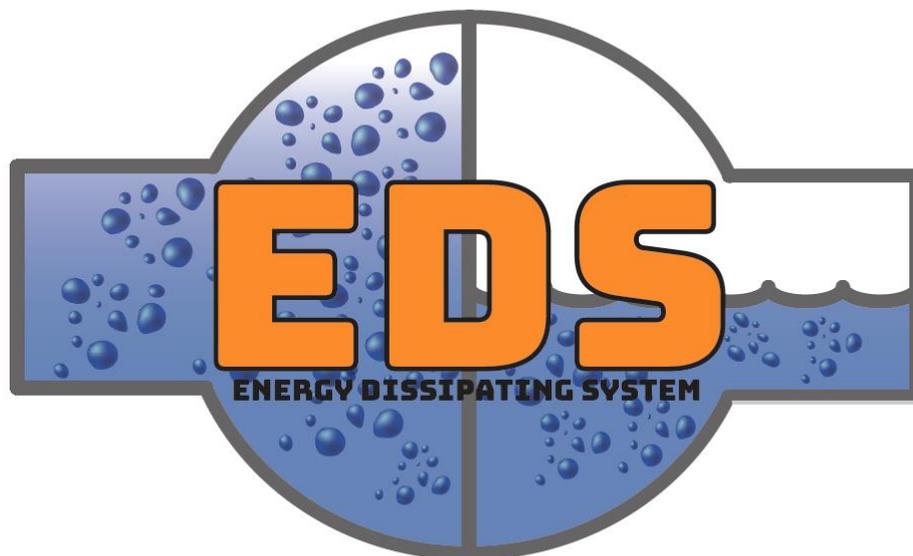


Multiconsult

Design of bypass valve

Appendix A: Requirement specifications

22.05.2018



GROUPMEMBERS	SUPERVISORS
MARKUS HJELLSETH	EXTERNAL SUPERVISOR: BJARNE BØRRESEN
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Abstract

The requirement specification is a list of requirements the system must, should or can satisfy depending on the priority of each requirement. Each requirement is derived from either stakeholders or use-case scenarios.

Document history

Version	Date	Author	Description
0.1	04.01.2018	LH	<ul style="list-style-type: none">• Preliminary work on requirement description and notation
0.2	26.01.2018	LH	<ul style="list-style-type: none">• Redefining requirements after meeting with MC• Writing business drivers
0.3	30.01.18	OO	<ul style="list-style-type: none">• Added test and risk links from the requirements
1.0	01.02.18	MH	<ul style="list-style-type: none">• Final edit and proofreading
1.1	07.05.18	LH	<ul style="list-style-type: none">• Revised the requirement form and removed the proposed requirements
2.0	19.05.18	OO	<ul style="list-style-type: none">• Proofread• Changed the reference setup

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1 Introduction

The requirements for the project is compiled from requirements set by Multiconsult and guidelines set by the government. These requirements, describes how the system shall function and in which environment. Some of the requirement depends on different design choices and will thus be developed throughout the project.

2 Purpose

The purpose of the requirement specification sheet is to achieve a thorough understanding of the requirements surrounding the system and to ensure the stakeholders that the system we create is valid.

3 Requirement notation

3.1 Requirement classes

Each requirement is rated according to its priority. They are divided into three categories, A, B and C requirements.

Priority	Description
A- must	A requirements MUST be satisfied, high priority
B- should	B requirements SHOULD be satisfied
C- can	C requirements CAN , low priority

Table 37: Requirement classes

3.2 Traceability

Each requirement must clearly state what the origin of the requirement is to achieve traceability and to ensure each requirement is needed.

3.3 Requirement form

Under is an example of how each requirement is notated. Each requirement is given a name based on the priority. For example, RQ-1.1 where RQ tells us that it is a requirement and the number tells us what requirement it is, in this case it is the first. Each requirement has a number, and the same number cannot be used again for another requirement.

Req-ID	Priority	Date	Owner	Type
Unique ID for each requirement	Priority for the requirement	Date for creation	Who required the requirement	Type of requirement, i.e. functional or formal
<p>Description: A tangible, concise and testable description of the requirement.</p>				

Table 38: Requirement form

For example, if we had a stakeholder requirement that the system will operate in an environment between 100-300 water column pressure, a system requirement derived from this could be:

Req-ID	Priority	Date	Owner	Type
RQ-1.1	A	10.01.18	MC	Functional
Description: The system MUST operate under the pressure of 100- to 300-meter water column.				

Table 39: Example requirement

3.4 Changes in requirements

When changes are made to the requirements it must be documented in order to see the development of the system. When a requirement is changed it shall be noted as below.

Req-ID	Priority	Date	Owner	Type
RQ-1.1	A	10.01.18	MC	Functional
Description: The system MUST operate under the pressure of 100- to 300-meter water column. The system MUST operate under the pressure of 150- to 300-meter water column.				

Table 40: Change in a requirement

If a requirement is removed completely it shall be noted as below

Req-ID	Priority	Date	Owner	Type
RQ-1.1	A	10.01.2018	MC	Functional
Description: The system MUST operate under the pressure of 100- to 300-meter water column. Removed				

Table 41: Removal of a requirement

4 Business drivers

Bypass facilities often use plunger valves, and this makes them expensive to build. In smaller hydropower plants where it is a requirement for a bypass facility this can lead to the plant having a smaller or no profit-margin, making the plant obsolete.

Our design goal is to parametrize a valve that is less expensive than current alternatives and still fulfills applicable guidelines.

5 Stakeholder requirements

Multiconsult has given a set of functional and formal requirements listed below. They are imperative to stakeholder acceptance of the system and are thus highly priorities.

5.1 Functional requirements

Category	Description
Pressure	100-300m
Water flow rate	0.5-3m ³ /s
Steering	Able to control water flow rate and have predictable characteristics.
Cavitation	Either design against cavitation or provoke cavitation on easily changeable parts
Surrounding conditions	Maximum velocity for water at valve exit 10 m/s
Strength	Satisfying mechanical strength

5.2 Non-functional requirements

Category	Description
Strength	Strength calculations are done in compliance with current standards
Production	Fabrication friendly (documented sketch for production)
Cost	Cost analysis associated with production
Remote control	Must be remotely controlled
HMS/ Security	HMS analysis for third-party companies

6 System Requirements

Req-ID	Priority	Date	Owner	Type
RQ-1	A	18.01.2018	MC	Functional
Description: The system MUST operate under the pressure of 100- to 300-meter water column.				
Test:		T-1	Risk:	RI-2.01

Req-ID	Priority	Date	Owner	Type
RQ-2	A	18.01.2018	MC	Functional
Description: The system MUST operate with a flow rate up to $3 \text{ m}^3/\text{s}$				
Test:		T-1	Risk:	RI-2.02

Req-ID	Priority	Date	Owner	Type
RQ-3	A	18.01.2018	MC	Functional
Description: The system MUST have a predictable flow characteristic				
Test:		T-2	Risk:	RI-2.03

Req-ID	Priority	Date	Owner	Type
RQ-4	A	18.01.2018	MC	Functional
Description: The system MUST manage cavitation satisfactorily				
Test:		T-3	Risk:	RI-2.04, RI-2.05

Req-ID	Priority	Date	Owner	Type
RQ-5	A	18.01.2018	MC	Functional
Description: Maximum velocity in the pipeline MUST not exceed 10 m/s				
Test:		T-4	Risk:	RI-2.06

Req-ID	Priority	Date	Owner	Type
RQ-6	A	18.01.2018	MC	Functional
Description: The system MUST have satisfactory mechanical strength according to applicable guidelines				
Test:		T-2, T-5	Risk: RI-2.07, RI-2.08	

Req-ID	Priority	Date	Owner	Type
RQ-7	B	18.01.2018	MC	Non-functional
Description: A cost analysis associated with production MUST be done Production costs SHOULD be lower than the current alternatives				
Test:		T-6	Risk: RI-2.13	

Req-ID	Priority	Date	Owner	Type
RQ-8	A	18.01.2018	MC	Non-functional
Description: The system MUST be able to remote control the valve in compliance with guidelines from NVE The system MUST be controlled autonomously in compliance with guidelines from NVE				
Test:			Risk: RI-2.14	

Req-ID	Priority	Date	Owner	Type
RQ-9	A	18.01.2018	MC	Non-functional
Description: HMS analysis for third party companies, The System MUST be regulated in compliance with "maskinforskriften".				
Test:			Risk: RI-2.09	

Req-ID	Priority	Date	Owner	Type
RQ-10	B	18.01.2018	MC	Non-functional
Description: The system SHOULD be scalable.				
Test:			Risk: RI-2.10	

6.1 Requirement proposal

Req-ID	Priority	Date	Owner	Type
RQ-X	X	31.01.2018	PG	Non-functional
Description: An actuator must be able to connect to the system				
Test:		Risk:		

Req-ID	Priority	Date	Owner	Type
RQ-X	X	31.01.2018	PG	functional
Description: Applied force from an actuator on the system should result in change in flow rate.				
Test:		Risk:		

Req-ID	Priority	Date	Owner	Type
RQ-X	X	31.01.2018	PG	Non-functional
Description: Surfaces that are in contact with water should be corrosion resistant				
Test:		Risk:		

Req-ID	Priority	Date	Owner	Type
RQ-X	X	31.01.2018	PG	
Description: The system MUST be able to deal with permanent, variable and accident loads.				
Test:		Risk:		

Req-ID	Priority	Date	Owner	Type
RQ-X	X	08.02.2018	PG	
Description: The system must be able connect to a pipeline with a diameter of XX mm.				
Test:		Risk:		

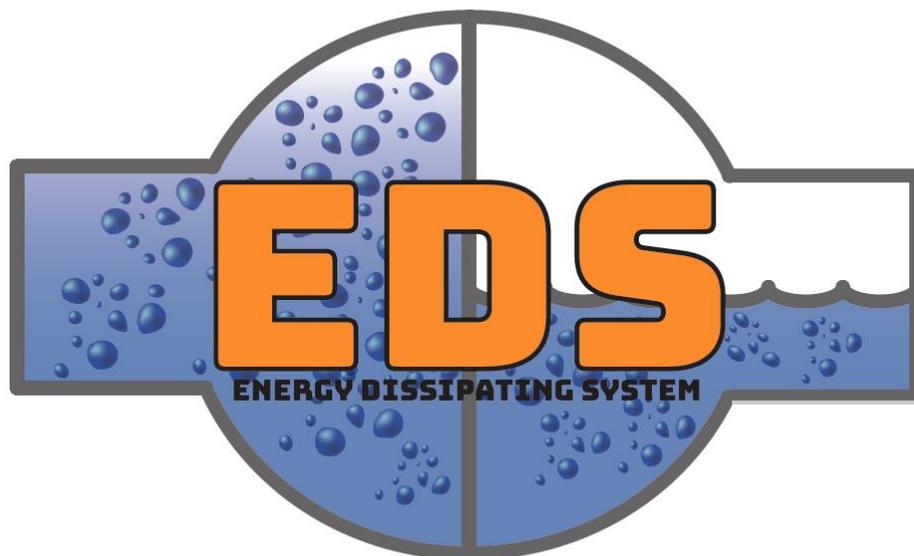
Req-ID	Priority	Date	Owner	Type
RQ-X	X	08.02.2018	PG	C
Description: The system can use standardized bolts and nuts in compliance with NS-EN XXXX				
Test:		Risk:		

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Design of bypass valve

Appendix B: Test specifications

22.05.2018



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Abstract

The test specification describes what tests are related to our project. How the requirements and risks are assessed to create test, the testing methods and how the tests are carried out and data is collected. The different tests are included.

Document history

Version	Date	Author	Description
0.01	30.01.18	LH, OO	<ul style="list-style-type: none">• Creating the document• Creating test cards• Adding tests
0.02	31.01.18	LH, OO, MH	<ul style="list-style-type: none">• Adding description• Adding tests• Adding chapter 2,3,4,5
1.00	01.02.18	LH	<ul style="list-style-type: none">• Adding abstract and finalizing the document for 1.0
2.00	19.05.18	OO	<ul style="list-style-type: none">• Proofread• Changed reference setup

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1 Introduction

The verification process is always a compromise, balancing rigorous testing against the cost and the time it takes to perform the tests (Richard, Brook, Jackson, & Arnold, 1998, p. 133). Testing everything will take too much time and is too expensive. Therefore, tests must be designed to effectively detect faults and to establish that the requirements are fulfilled.

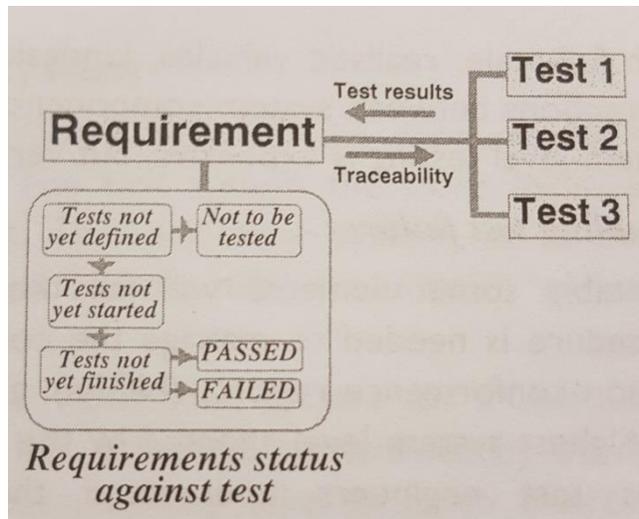


Figure 210: Requirement status and tests (Richard, Brook, Jackson, & Arnold, 1998, p. 137)

To verify the design of the valve the group has decided to use verification by analysis, since our final goal is to produce a parametrized valve design and not a physical part. The group will use **design verification** to ensure that the requirements are met if the product is appropriately manufactured. A single requirement may need to be verified at several levels with different tests (Richard, Brook, Jackson, & Arnold, 1998, pp. 136, 137). For example, a control shaft in the valve may be tested as only the shaft, in combination with the valve, attached to the control system or with

both in a complete system. Figure 1 shows how a single requirement is related to several tests. The status of requirement changes with respect to its tests as the tests are defined, and the results emerge. For example, the status may step between test is not defined, not yet started, pass and fail. Links between requirements and test are used to analyze test status of the requirement.

Each test will produce a test report with an in-depth explanation of the test, testing method, collecting data, test status and eventual suggested modification to the test or design if the test failed.

2 From requirements to testing

Each requirement is created to make sure the system leads to stakeholder acceptance. The testing process confirms whether the system fulfills these requirements. The group will carry out the tests as described in *Figure 1*.

2.1 Plan test

This activity involves planning the tests. Analyzing the requirements to create relevant tests is essential. One test may check several requirements, and one requirement may require several tests, depending on the requirement. It's vital to ensure requirement traceability to determine if every requirement has been tested.

It's almost impossible to thoroughly test the system without creating the entire system and checking it in a real-life simulation, so doing test planning generally involves identifying cases, procedures, and testing components to make sure each one fulfills the requirement. (Scott, 2002, s. 82)

There are two basic strategies when planning the tests.

- Conformance-directed testing
 - The focus is on feature sufficiency, to establish conformance to the customer requirements.
- Fault-directed testing
 - The focus is on fault efficiency. The tests are planned to have a high chance to reveal system faults. For example, stress testing the system.

2.2 Design test

This activity involves the process of designing the test. How the test shall be carried out and how to record the result data are relevant questions within test design (Scott, 2002, s. 82). The test should be designed to reuse previous test procedures to save time. Each test should also be made as simple as possible. This will not only save time but will also often lead to more conclusive and definite answers.

2.3 Test

During this activity, the tests shall be carried out in compliance with the test specification. The test manager shall oversee every test to ensure correct testing and correct collection of test data.

2.4 Evaluate

After the completion of a test, the result shall be evaluated to ensure that the test was successful and that the associated system requirements have been tested sufficiently.

The testing method shall be evaluated whether or not the test passed or not to ensure that the results are correct. If the testing method was invalid, the test design should be altered to record data and test the requirement properly. If the test failed and the testing method was

valid, the design shall be altered to pass the test. The figure below shows the flowchart for each test.

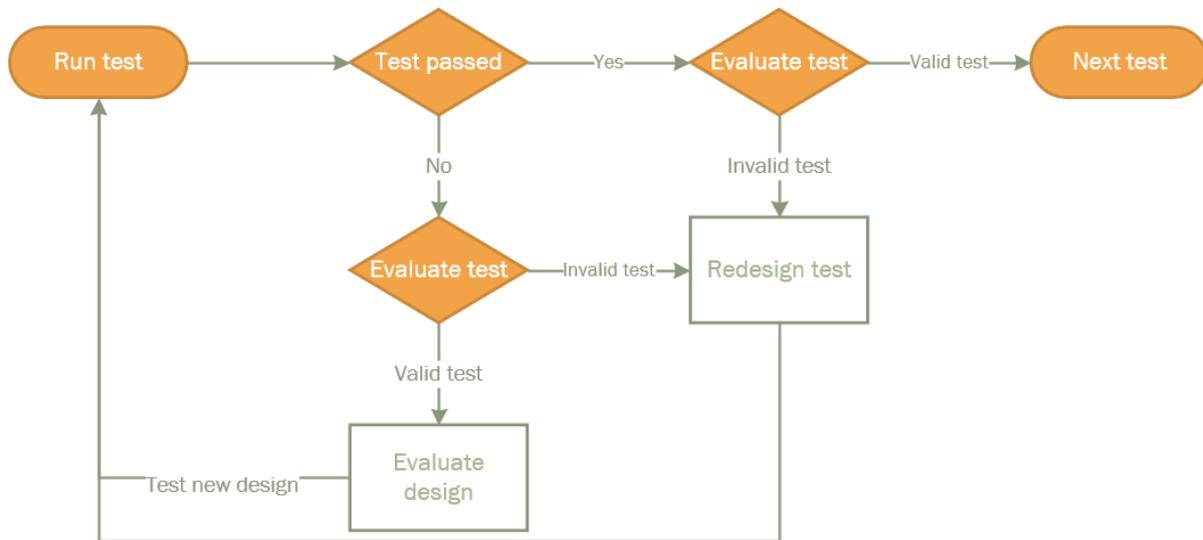


Figure 211: Test flowchart

2.4.1 Handling test failures

Inevitably some design elements will fail their tests, and a procedure needs to be in place once this happens (Richard, Brook, Jackson, & Arnold, 1998, p. 138). Failures will be documented in the test rapport. Here it will be a description of the failure, if it was test related or design related and the consequences of the failure if it's not corrected. There will also be documented changes to the testing method if the test was the reason for failure, or recommendations for design modifications if the design was faulty.

3 Test methods

Seeing as the group won't deliver an actual valve, but rather a design with complete calculations, models, and analyses, tests on the real product will be impossible. The group will, therefore, rely heavily on theoretical tests and tests based on SolidWorks. The group might get the chance to 3D-print subsystems, in which case some tests will be performed on the printed models.

Analyzing

Analyzing is probably the test method that will be conducted most. SolidWorks is a CAD program that has several analyzing methods that will be relevant to our project. The methods that will be used are:

- FEM (Finite element method): This type of simulations gives the opportunity to conduct static, thermal and frequency tests.
- Flow analysis: This analyze method gives us the opportunity to analyze fluid flowing through the system.
- The group will also use ANSYS Fluent, one of the most powerful CFD solvers available which use the Finite Volume Method in a wide range of applications.
- Autodesk Inventor Professional will also be used for static, dynamic, thermal and vibration tests.

Certification

Certification is a method used to verify requirements for standard products. An example could be to use standardized bolts. If this product has a certification, the group can control if the product is approved according to our requirements. This is a method that can save us a lot of time. Standardization will, therefore, be of importance in this project.

Demonstration

This is a test method that can be a great tool in the period where development phase of the concepts. When designing different concepts, it can be difficult to fully comprehend each system. A result of this might be the insertion of incorrect forces or parameters when analyzing. By making a demonstration of a 3D printed prototype, it will be easier to get a correct understanding of the forces acting on the system.

4 Test plan

The purpose of the test plan is to describe a test that will verify one or more requirements. The plan will contain which test method will be used, a description of how the test will be executed and what the acceptance criteria are. The tests will also be prioritized in order to focus on the most critical tests first. How the group will prioritize the test is explained in the next chapter.

4.1 Test Priority

$$\text{Requirement priority} * \text{risk number} = \text{Test priority}$$

Requirement priority

The test priority is based on risk and requirement priority. To be able to multiply these values the group need to make the requirements priority into numerical values. *Table 1* shows the numerical values of the letter priorities.

Requirement priority	Numerical value
A	3
B	2
C	1

Table 42: Requirement priority

If a test is linked to several requirements, the test priority will be based on the requirement with the highest priority.

Risk number

Each requirement has one or more risks. These risks have a related risk number, where 25 is a high risk, and 0 is a low risk. If there are several risks to one requirement, the group will base the test priority on the highest risk.

Test priority

By multiplying risk and requirement, the group will end up with a number between 0 and 75. The priority is addressed with the letters A, B and C. Shown below is a table that shows the relationship between the letters and the numerical value.

Test priority	Numerical value
A	75-50
B	49-25
C	24-0

Table 43: Test priority

4.2 Test table

Test ID	Requirement Value	Risk value	Test value	Test priority
T-1	3	20	60	A
T-2	3	12	36	B
T-3	3	8	24	B
T-4	2	8	16	C
T-5	3	16	48	B
T-6	2	8	16	C

Table 44: List of tests

4.3 Testcard/ test logs

Test ID:	T-1	Priority	A
Requirements tested	RQ-1, RQ-2	Date	30.01.18
Test method:	Flow analysis		
Test description: Operation			
This can be done using flow analysis by putting the parameters given by RQ-1, and a velocity of 10 m/s then run the simulation. By analyzing a section downstream, the group can get a value of the flow rate.			
Acceptance criteria			
The system has a flow rate up to $3 \text{ m}^3/\text{s}$			
Result:	TEST PASS		

Test ID:	T-2	Priority	B
Requirements tested	RQ-3, RQ-6	Date	30.01.18
Test method:	Flow analysis		
Test description:			
Test flow rate on different settings numerous times and plot them in a graph.			
Acceptance criteria			
Every part of the system withstands the pressure. No plastic deformation should occur. Minimal degrees of elastic deformations can occur, but the system must remain operational.			
Result:	TEST PASS		

Test ID:	T-3	Priority	B
Requirements tested	RQ-4	Date	30.01.18
Test method:	Flow analysis		
Test description: Cavitation			
This can be done by using flow analysis by putting the parameters given by RQ-1 and RQ-2 and run the simulation. By studying the velocity- and pressure chart the group can predict if there occurs cavitation and where.			
Acceptance criteria			
Alternative 1: Cavitation is not occurring			
Alternative 2: Cavitation is occurring in a place where it doesn't do any damage			
Alternative 3: Cavitation is occurring on a predicted wear part			
Result:	TEST PASS		

Test ID:	T-4	Priority	C
Requirements tested	RQ-5	Date	31.01.18
Test method:	FEM		
Test description: velocity			
Use a flow simulation program. Run the simulation with the operational parameters. Check the outlet velocity.			
Acceptance criteria			
The velocity is under 10 m/s			
Result:	TEST PASS		

Test ID:	T-5	Priority	B
Requirements tested	RQ-6	Date	31.01.18
Test method:	FEM		
Test description:			
Metal parts that are in contact with the water will be tested using FEM. Forces equivalent to 300meter water column will be applied to expected areas.			
Acceptance criteria			
The metal parts must have a satisfactory safety factor according to the standards: Cast iron: NS-EN 1563 Steel: NS-EN 10025-3 Aluminum: EN-AW-6082 / 6060			
Result:	TEST PASS		

Test ID:	T-6	Priority	C
Requirements tested	RQ-7	Date	31.01.18
Test method:	Mathematical Calculations		
Test description:			
Calculate the production-cost of existing valves. Compare price to our system. Cost estimate of our system will be based on experience and Solidworks.			
Acceptance criteria			
Our system is cheaper that 70% of existing valves.			
Result:	TEST FAIL		

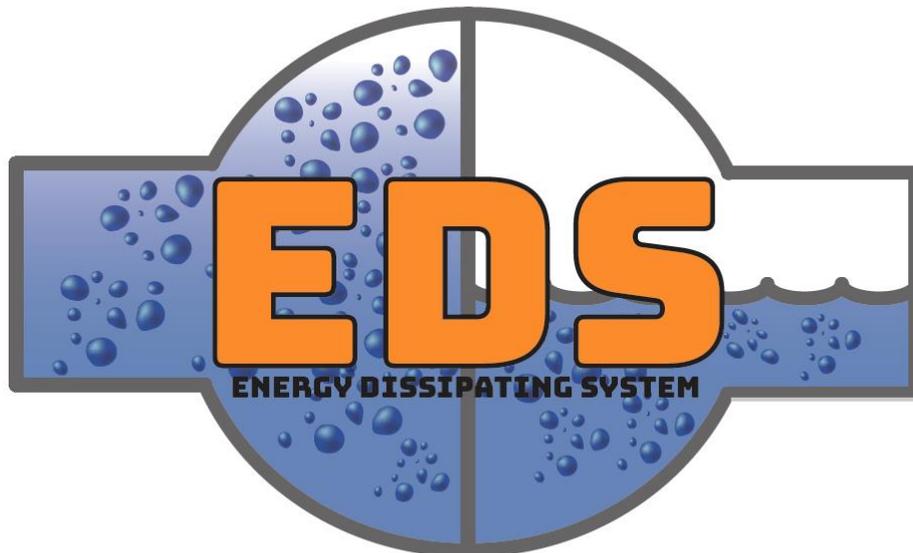
Test ID:	T-7	Priority	B
Requirements tested	RQ-10	Date	31.01.18
Test method:	SolidWorks		
Test description:			
Test the system by changing the input pressure to PN25 and PN64.			
Acceptance criteria			
The system operates in the same way as in the original size.			
Result:	TEST FAIL		

Multiconsult

Design of bypass valve

Appendix C: Risk analysis

22.05.2018



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Abstract

Background: Project work involves foreseeing and preventing risks from making an impact on the project. In order to be aware of these risks a risk analysis is conducted.

Method: The analysis consists of four parts, identification, severity and probability, consequences and measures. The risks is divided into two groups, project work related risks and system related risks. The risks identified in the identification part is put into a severity and probability matrix and the numbers that the risk receive in the two categories is multiplied. This number is the total risk. Each risk is also analyzed to find the consequences and measures that can be applied to lower the total risk number.

Results: Total 14 system related risks and 12 project related risks were discovered. Each one has consequences and measures related to them. The risks were evaluated throughout and at the end of the project. Risks were added into the risk analysis as they were discovered during the project. The fact that the group was aware of the risks and implemented measures to prevent them was helpful.

Document history

Version	Date	Author	Description
0.01	19.01.18	MH	<ul style="list-style-type: none"> • Making of the document
0.02	21.01.18	MH	<ul style="list-style-type: none"> • Finished system risks
0.03	23.01.18	MH	<ul style="list-style-type: none"> • Editing various texts
0.04	25.01.18	MH	<ul style="list-style-type: none"> • Added Project Risks from Project Plan
0.05	31.01.18	OO, MH	<ul style="list-style-type: none"> • Proofreading • Updated system risks • Adding references
1.00	01.02.18	MH	<ul style="list-style-type: none"> • Final edit before printing • Fixed page layouts
1.01	18.05.18	JS	<ul style="list-style-type: none"> • Proofread
2.00	19.05.18	LH	<ul style="list-style-type: none"> • Proofreading • Added abstract

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1 Goal

The goal of the analysis is to chart what the risks are, how severe they are, the probability of them happening, what can be done to avoid it, and what can be done if it should happen. When designing the system, this analysis will be a great tool to make sure that the group avoids certain mistakes. It will also help the group by saving time.

The difference between the risk analyses for the system and for the project, is that the system risks are heavily linked to the requirements.

1.1 Analysis

The risk analysis consists of four parts: identification, severity and probability, consequences and measures.

In the identification part, the goal is to identify the risks (Kerzner, 2009, p. 755). Seeing as the risks for the system are heavily linked to the requirements, multiple risks appeared naturally. After evaluating the risks, the risks that need further considering will be analyzed by the group. The risk selection will be based on the severity and probability of the risk.

In the severity and probability part, an evaluation will be made to determine the impact and likelihood of a risk, should it come through and happen. By knowing what risks have the highest impact on the system, and what risks are likely to occur, these risks can be completely avoided or at least mitigated.

By knowing the consequences, it's easier to take actions to prevent the risks. A single risk can naturally have many different consequences.

The measures to be taken, depends on the severity of the risk (Kerzner, 2009, p. 753). If the severity is of such a high grade that it would ruin the system or project, the risk must be avoided. If it's something that won't affect the system or project in a major way, it will be mitigated or simply monitored. Measures like this must be taken to minimize the risk, and to prevent accidents and failures.

1.2 The matrix

To evaluate each risk, two parameters will be used: probability and severity. Each parameter ranges from 1 to 5, where 5 indicates the highest probability or severity. If a risk has a high probability, it means that it is likely to occur. If a risk has high severity, it means that the impact it has on the system or project will be big. These two parameters will be multiplied with each other to produce a final number. The final number indicates the total risk. A high final number means that the risk has a high probability, and a high severity. Indicating that it must be dealt with.

The matrix is split into 25 bits, which all are color-coded. Each color indicates the severity of the risk.

- Green means low numbers and that the risk is ok without a problem.
- Light green is low-medium numbers, these risks are ok but should be monitored.
- Yellow for moderate numbers and means that it should be considered.
- Orange means medium-high numbers. These risks are not ok and should be looked further into.
- Red indicating high numbers, and that it must be handled.

Probability \ Severity	1	2	3	4	5
1	1	2	3	4	5
2	2	4	6	8	10
3	3	6	9	12	15
4	4	8	12	16	20
5	5	10	15	20	25

Table 45: Risk matrix

1.3 Analyzing matrix

The analysis of each of the chosen risks will be done by using the card shown below (Table 46). The card includes risk ID, requirement that is linked to the risk, the risk itself, why it is a risk, probability, severity, final risk number, consequence and action to be made. With these simple points, a thorough analysis can be made.

Risk analysis template:

Risk ID: XXXX	
Requirement	The requirement that the risk is linked to, if it is linked to one.
Risk	Describes the risk being analyzed.
Why?	Why is it a risk? What can go wrong?
Probability	The probability of the risk happening
Severity	The severity of the risk
Risk number	The two parameters multiplied with each other. Final number.
Consequences	Consequences of the situation happening.
Actions	What actions can be made to prevent or minimize the impact of the situation.

Table 46: Risk card

2 System risks

As it is the requirements that define the guidelines for the design of the system, they naturally play a major role when it comes to the risks. Most of the system risks are therefore based heavily on, or directly connected, to the requirements. If the system fails a requirement, it would be detrimental to the system as well as the entire project. Because of this, most of the risks linked to the requirements, have a high score in the severity parameter.

Risk ID	Risk
RI-2.01	The system is not able to hold a water-column of 100 to 300 meter.
RI-2.02	The system can't withstand a flowrate up to $3 \text{ m}^3/\text{s}$.
RI-2.03	Can't control the system flow rate.
RI-2.04	The system isn't resistant to cavitation.
RI-2.05	The areas where cavitation occurs aren't changeable.
RI-2.06	Velocity at the exit of the system exceeds 10 m/s.
RI-2.07	The system isn't satisfactory when it comes to mechanical strength.
RI-2.08	The system is not in compliance with the guidelines from NVE.
RI-2.09	The system does not pass basic safety standards

RI-2.10	The system is not scalable.
RI-2.11	The system isn't fabrication friendly.
RI-2.12	The fabrication documents don't hold an acceptable standard.
RI-2.13	The system costs more to produce than existing systems.
RI-2.14	The system can't be controlled from a remote location.
RI-2.15	Analyses are inaccurate
RI-2.16	Poor design choices.

Table 47: System risks

2.1 System risk Analyses

Below, the group has analyzed the chosen risks:

Risk ID: RI-2.01	
Requirement	RQ-1: The system MUST operate under the pressure of a 300-meter water column.
Risk	The system is not able to hold a water-column of 300 meter.
Why?	<ul style="list-style-type: none"> • Wrong material • Wrong strength calculations
Probability	1
Severity	4
Risk number	4
Consequences	<ul style="list-style-type: none"> • If it can't withstand the pressure of a water-column this size, the system will not be suitable for its intended use. • Won't be produced.
Actions	<ul style="list-style-type: none"> • Make thorough analyses to make sure that the system can handle the pressure. • Improve the design

Risk ID: RI-2.02	
Requirement	RQ-2: The system MUST operate with a flow rate up to $3 \text{ m}^3/\text{s}$
Risk	The system can't withstand a flow rate up to $3 \text{ m}^3/\text{s}$.
Why?	<ul style="list-style-type: none"> • The mechanism in the system is not strong enough. • The system is too small for the facility.
Probability	3
Severity	4
Risk number	12
Consequences	<ul style="list-style-type: none"> • If the system can't handle this flowrate, it won't allow enough water to pass downstream, thereby defying criteria's set by NVE.
Actions	<ul style="list-style-type: none"> • Keep the mechanism simple. • Making the system in different sizes will most likely handle this problem.

Risk ID: RI-2.03	
Requirement	RQ-3: The system MUST have a predictable flow characteristic
Risk	Can't control the systems flow rate.
Why?	<ul style="list-style-type: none"> • Mechanism gets stuck. • Faulty design.
Probability	2
Severity	3
Risk number	6
Consequences	<ul style="list-style-type: none"> • Can't control the amount of water running through, which in turn can lead to catastrophe. • If the flow rate is not controllable, the whole point of the system is meaningless.
Actions	<ul style="list-style-type: none"> • The mechanism that controls the flowrate must be solid and proven. • Have a failsafe-function?

Risk ID: RI-2.04	
Requirement	RQ-4: The system MUST manage cavitation satisfactorily
Risk	The system isn't resistant to cavitation.
Why?	<ul style="list-style-type: none"> • Faulty design • The system is not tested enough
Probability	2
Severity	5
Risk number	10
Consequences	<ul style="list-style-type: none"> • If the system is exposed to cavitation, the structural integrity of the system is severely lowered. • System can break long before end of expected lifetime.
Actions	<ul style="list-style-type: none"> • Do thorough testing. • Make sure the vacuum (which in turn, turns into cavitation), happens in the middle of the pipe or system. • The cavitation only happens on changeable parts.

Risk ID: RI-2.05	
Requirement	RQ-4: The system MUST manage cavitation satisfactorily
Risk	The areas where cavitation occur aren't changeable.
Why?	<ul style="list-style-type: none"> • Haven't tested the system enough to see where the cavitation occurs. • Too complex design, making it hard to change parts.
Probability	2
Severity	5
Risk number	10
Consequences	<ul style="list-style-type: none"> • System can break long before end of expected lifetime. • Too dangerous to use system, leaving it unviable.
Actions	<ul style="list-style-type: none"> • Do thorough testing. • Make the parts that needs to be changed easy to access.

Risk ID: RI-2.06	
Requirement	RQ-5 Maximum velocity in the pipeline MUST not exceed 10 m/s.
Risk	Velocity in the pipeline exceeds 10 m/s.
Why?	<ul style="list-style-type: none"> • The mechanism isn't good enough.
Probability	2
Severity	4
Risk number	8
Consequences	<ul style="list-style-type: none"> • If the velocity exceeds 10 m/s at the exit of the system, the water will cause to much destruction to the immediate surroundings downstream. • Can't be used in Norway (maybe other guidelines in other countries).
Actions	<ul style="list-style-type: none"> • Make sure the velocity is well below 10 m/s. • Use a safety margin?

Risk ID: RI-2.07	
Requirement	RQ-6: The system MUST have satisfactory mechanical strength according to applicable guidelines
Risk	The system isn't satisfactory when it comes to mechanical strength.
Why?	<ul style="list-style-type: none"> • Used wrong materials. • The design is faulty.
Probability	4
Severity	4
Risk number	16
Consequences	<ul style="list-style-type: none"> • The system can't be used for its intended purpose.
Actions	<ul style="list-style-type: none"> • Make it strong enough.

Risk ID: RI-2.08	
Requirement	RQ-6: The system MUST have satisfactory mechanical strength according to applicable guidelines
Risk	The system is not in compliance with the guidelines from NVE.
Why?	<ul style="list-style-type: none"> • The system oversteps one or more of the guidelines set by NVE. • The group hasn't comprehended the guidelines. • The group has overlooked the guidelines.
Probability	3
Severity	4
Risk number	12
Consequences	<ul style="list-style-type: none"> • The system won't be legal in Norway. • Won't be produced.
Actions	<ul style="list-style-type: none"> • Make sure the group has fully understood the guidelines before designing.

Risk ID: RI-2.09	
Requirement	RQ-9: HMS analysis for third party companies.
Risk	The system does not pass basic safety standards.
Why?	<ul style="list-style-type: none"> • Safety hasn't been thought of when designing. • The group isn't aware of the safety standards.
Probability	4
Severity	5
Risk number	20
Consequences	<ul style="list-style-type: none"> • The system will be too dangerous to operate. • Injuries or worse.
Actions	<ul style="list-style-type: none"> • Keep the safety of the user in mind when designing. • Research safety standards.

Risk ID: RI-2.10	
Requirement	RQ-10: The system SHOULD be scalable.
Risk	The system is not scalable.
Why?	<ul style="list-style-type: none"> • To complex design. • Some features won't work in other sizes.
Probability	4
Severity	2
Risk number	8
Consequences	<ul style="list-style-type: none"> • The system can only be used in facilities that fit the system-size. • Must redesign the system to make it scalable.
Actions	<ul style="list-style-type: none"> • Keep the design simple. • Do calculations for multiple system-sizes.

Risk ID: RI-2.13	
Requirement	RQ-7: Production costs SHOULD be lower than the current alternatives.
Risk	The system costs more to produce that existing systems.
Why?	<ul style="list-style-type: none"> • Too complex design. • Material costs are too high. • Can't find a cheap way to produce the system.
Probability	2
Severity	4
Risk number	8
Consequences	<ul style="list-style-type: none"> • The system will be too expensive. • The customers will go for the other alternatives.
Actions	<ul style="list-style-type: none"> • Make sure that the system is the cheapest option.

Risk ID: RI-2.14	
Requirement	RQ-8: The system MUST be able to remote control the system in compliance with guidelines from NVE.
Risk	The system can't be controlled from a remote location.
Why?	<ul style="list-style-type: none"> • Not enough knowledge on remote technology. • Forget to implement it.
Probability	2
Severity	3
Risk number	6
Consequences	<ul style="list-style-type: none"> • The system will have to be operated manually.
Actions	<ul style="list-style-type: none"> • Implement remote technology.

Risk ID: RI-2.15	
Requirement	n/a
Risk	Analyses are inaccurate.
Why?	<ul style="list-style-type: none"> • Not enough knowledge on the subject • Not enough experience in using the tool (Solidworks, FLUENT).
Probability	3
Severity	5
Risk number	15
Consequences	<ul style="list-style-type: none"> • Wrong output from analyses • Faulty design because of wrong input from analyses.
Actions	<ul style="list-style-type: none"> • Have multiple group members doing it. • Ask external supervisors.

Risk ID: RI-2.16	
Requirement	n/a
Risk	Poor design choices.
Why?	<ul style="list-style-type: none">• Faulty information given by analyses• Inexperience in the field• Hasty decision-making due to deadlines
Probability	3
Severity	3
Risk number	9
Consequences	<ul style="list-style-type: none">• Faulty system• The system will not be produced
Actions	<ul style="list-style-type: none">• Constantly consult with external supervisors.• Have group meetings revising the current design.

2.2 The System Risk Matrix

When putting the risks back into the risk matrix, it's easy to see which risks should be looked deeper into and handled, and which risks are fine. When looking at each risk in this matrix, it appears more clearly in which of the two parameters the risks needs improvement. The model below will overall provide a more visual presentation of in which state the risks are.

Probability \ Severity	1	2	3	4	5
1					
2				RI-2.10	
3		RI-2.12, RI-2.03, RI-2.14	RI-2.16		
4	RI-2.01,	RI-2.06, RI-2.11, RI-2.13	RI-2.02, RI-2.08	RI-2.07	
5		RI-2.04, RI-2.05,	RI-2.15	RI-2.09	

Table 48: System Risk Matrix

3 Project Risk

The risks for the project are mostly focused on the group, and the partners involved. These risks are not linked to a requirement, "n/a" will therefore be written in the requirement-box.

Risk ID	Risk
RI-1.01	Multiconsult backing out of the project.
RI-1.02	Group member being sick over an extended period.
RI-1.03	Loss of documents.
RI-1.04	Language-barrier leading to misunderstandings.
RI-1.05	Internal deadlines not being met.
RI-1.06	External deadlines not being met.
RI-1.07	Scope of assignment is bigger than expected.
RI-1.08	Low motivation in group.
RI-1.09	Don't get access to necessary equipment for testing etc. in the workshops.
RI-1.10	Disagreement within the group, or towards external supervisors.
RI-1.11	Group members deliver different quality of work.
RI-1.12	Difference in amount of work put down.

3.1 Project risk analyses:

Risk ID: RI-1.01	
Requirement	n/a
Risk	Multiconsult backing out of the project.
Why?	<ul style="list-style-type: none"> • Not satisfied with the work that the group are doing. • Internal reasons.
Probability	1
Severity	5
Risk number	5
Consequences	<ul style="list-style-type: none"> • Stop the collaboration with Multiconsult. • Project stops
Actions	<ul style="list-style-type: none"> • Find a new project • Carry on with the project, without Multiconsult.

Risk ID: RI-1.02	
Requirement	n/a
Risk	Group member being away for an extended period.
Why?	<ul style="list-style-type: none"> • Vacation • Sickness • Personal issues
Probability	4
Severity	4
Risk number	16
Consequences	<ul style="list-style-type: none"> • Serious decrease in work force • Work will not be done
Actions	<ul style="list-style-type: none"> • Distribute the tasks between the remaining group members. • Notify Karoline Moholt about the situation

Risk ID: RI-1.03	
Requirement	n/a
Risk	Loss of documents
Why?	<ul style="list-style-type: none"> • Program error • Forgetting to save • Computer malfunction
Probability	1
Severity	4
Risk number	4
Consequences	<ul style="list-style-type: none"> • Will lose work that's been done • Cost extra time
Actions	<ul style="list-style-type: none"> • Save often • Keep backups

Risk ID: RI-1.04	
Requirement	n/a
Risk	Language-barrier leading to misunderstandings.
Why?	<ul style="list-style-type: none"> • Different native languages • None of the group members are fluent in English
Probability	4
Severity	2
Risk number	8
Consequences	<ul style="list-style-type: none"> • Misunderstandings • Using extra time • Lead to mistakes
Actions	<ul style="list-style-type: none"> • Be clear when communicating • Take time to discuss, make sure everyone understands.

Risk ID: RI-1.05	
Requirement	n/a
Risk	Internal deadlines not being met
Why?	<ul style="list-style-type: none"> • Bigger task than first anticipated • Unforeseen delays • Change in timeplan
Probability	3
Severity	2
Risk number	6
Consequences	<ul style="list-style-type: none"> • Will have to postpone further work • The group have to put in extra time
Actions	<ul style="list-style-type: none"> • Communicate with each other • Accept help if needed • Ask for help before it's too late

Risk ID: RI-1.06	
Requirement	n/a
Risk	External deadlines not being met
Why?	<ul style="list-style-type: none"> • Bigger task than first anticipated • Unforeseen delays • Change in timeplan
Probability	1
Severity	4
Risk number	4
Consequences	<ul style="list-style-type: none"> • Unsatisfied customer (Multiconsult) • Doesn't look good to HSN
Actions	<ul style="list-style-type: none"> • Be disciplined • Follow project-plan and Gantt diagram

Risk ID: RI-1.07	
Requirement	n/a
Risk	Scope of Assignment is bigger than expected.
Why?	<ul style="list-style-type: none"> • Underestimated the size of the project • Overestimated the work capacity of the group
Probability	4
Severity	4
Risk number	16
Consequences	<ul style="list-style-type: none"> • Not being able to finish the project • Finishing the project with a system the group is not satisfied with.
Actions	<ul style="list-style-type: none"> • Work efficiently • Have a good project-plan • Put in extra work-hours if needed

Risk ID: RI-1.08	
Requirement	n/a
Risk	Low motivation in group
Why?	<ul style="list-style-type: none"> • “boring” tasks • Monotonic assignments
Probability	1
Severity	3
Risk number	3
Consequences	<ul style="list-style-type: none"> • Decrease in work capacity and efficiency • Lowered quality of work
Actions	<ul style="list-style-type: none"> • Positive reinforcement • Take breaks • Celebrate when reaching a milestone

Risk ID: RI-1.09	
Requirement	n/a
Risk	Don't get access to necessary equipment, in workshop, for testing etc.
Why?	<ul style="list-style-type: none"> • Restricted access to workshop • Not qualified to use certain equipment • Workshop-supervisors are strict
Probability	4
Severity	3
Risk number	12
Consequences	<ul style="list-style-type: none"> • Can't perform desired tests
Actions	<ul style="list-style-type: none"> • Opt. for sub-optimal tests • Find other place to perform desired tests

Risk ID: RI-1.10	
Requirement	n/a
Risk	Disagreement within the group, or towards supervisors.
Why?	<ul style="list-style-type: none"> • Different prioritization • Sitting on different knowledge, understanding and information
Probability	4
Severity	3
Risk number	12
Consequences	<ul style="list-style-type: none"> • Will create a stressful work-environment.
Actions	<ul style="list-style-type: none"> • Have open discussions • All group members must be open minded

Risk ID: RI-1.11	
Requirement	n/a
Risk	Group members deliver different quality of work.
Why?	<ul style="list-style-type: none"> • Different backgrounds and expectations to ourselves
Probability	4
Severity	2
Risk number	8
Consequences	<ul style="list-style-type: none"> • Can create an inconsistent bachelor thesis. • More work will have to be done in the Transition phase of the project.
Actions	<ul style="list-style-type: none"> • Create standards • Proofread each other's work • Have a discussion regarding what goes into which document

Risk ID: RI-1.12	
Requirement	n/a
Risk	Difference in amount of work put down.
Why?	<ul style="list-style-type: none"> • Personal reasons / away from school • Different work-ethics
Probability	3
Severity	3
Risk number	9
Consequences	<ul style="list-style-type: none"> • Can create splits within the group • Unfair grading of bachelor thesis
Actions	<ul style="list-style-type: none"> • Divide tasks so that every group member does an equal amount of work • Keep an eye on the timesheets. Those who have the most hours can take a day off.

3.2 The Project Risk Matrix

When putting the risks back into the risk matrix, it's easy to see which risks should be looked deeper into and handled, and which risks are fine. When looking at each risk in this matrix, it appears more clearly in which of the two parameters the risks needs improvement. The model below will overall provide a more visual presentation of in which state the risks are.

Probability \ Severity	1	2	3	4	5
1			RI-1.08		
2			RI-1.05	RI-1.04 RI-1.11	
3		RI-1.03	RI-1.12	RI-1.09 RI-1.10	
4	RI-1.06			RI-1.07 RI-1.02	
5	RI-1.01				

Table 49: Project Risk Matrix

4 Evaluation

As seen above, there has been a lot of risks to this project, both concerning the system itself and the group. As the risks for this project were listed during the Elaboration phase, E1, it would be nearly impossible to predict every single risk to the project. Some risks were therefore added later in the project, as the group anticipated them or as they were happening.

Throughout the project it is helpful to evaluate the risks, that way they can be prevented in the future. This will not only help the progress of the project but will also give each group member valuable experience and insight within risk assessment.

4.1 Evaluation chart

When it comes to the design of the system, most of the risks have been avoided or handled properly. This is primarily due to the fact that most of the system risks originate from requirements set by Multiconsult. That being said, the risk analysis has certainly helped in the progress of the designing phase. By exploiting the work the group has already done, possible disasters were avoided.

Disasters regarding the group has also been avoided. By having thought of the risks before they occurred, the group were prepared to handle most situations.

All in all, the risk analysis has been a helpful tool throughout the project. With a little effort in the beginning of the project, the group was able to foresee multiple risks, and therefore avoiding or handling them. After the initial making of the analysis, very little work has been done to it, even though the group has used it at multiple occasions. It has simply been used as the tool that it is, and the group has been able to reap the benefits of having it.

Risk ID	Risk evaluation
RI-1.01	<p>Multiconsult backing out of the project.</p> <p>Multiconsult has become more and more involved in the project.</p>
RI-1.02	<p>Group member being sick over an extended period.</p> <p>No members have been sick, but some has been away for personal reasons.</p>
RI-1.03	<p>Loss of documents.</p> <p>Onedrive and local hard drives has been used to save documents.</p>
RI-1.04	<p>Language-barrier leading to misunderstandings.</p> <p>The language-barrier has not been an issue, as all members are virtually on the same level of English-knowledge.</p>

RI-1.05	<p>Internal deadlines not being met.</p> <p>Some internal deadlines were postponed or not met; the group then changed the project plan to accommodate for this.</p>
RI-1.06	<p>External deadlines not being met.</p> <p>All external deadlines have been met.</p>
RI-1.07	<p>Scope of assignment is bigger than expected.</p> <p>The project has been manageable, but due to inexperience in the field, the design has not been fully optimized.</p>
RI-1.08	<p>Low motivation in group.</p> <p>At times, the motivation in the group was low. Mostly related to analyses and documentation.</p>
RI-1.09	<p>Don't get access to necessary equipment for testing etc. in the workshops.</p> <p>Having some problems with software licenses. Biggest problem is not having access to various standards.</p>
RI-1.10	<p>Disagreement within the group, or towards external supervisors.</p> <p>These situations have for the most part been avoided as the group and supervisors has a common understanding of most subjects.</p>
RI-1.11	<p>Group members deliver different quality of work.</p> <p>Has occurred on multiple occasions but has not been a problem. The group members have helped each other to produce good documentation.</p>
RI-1.12	<p>Difference in amount of work put down.</p> <p>Some differences in time put into the project by each member has occurred. These differences are for the most part justifiable, so no real reason for concern.</p>
RI-2.01	<p>The system is not able to hold a water-column of 100 to 300 meter.</p> <p>Design changes were made so that the system would withstand the water column.</p>

RI-2.02	<p>The system can't withstand a flowrate up to 3 m³/s.</p> <p>Design changes were made to allow for a flowrate of 3 m³/s. system can handle it without problem</p>
RI-2.03	<p>Can't control the system flow rate.</p> <p>Flow rate is controllable. Close to linear flow characteristics. Room for improvement.</p>
RI-2.04	<p>The system isn't resistant to cavitation.</p> <p>The system is resistant to cavitation for the most part. Some cavitation might still occur in controlled places.</p>
RI-2.05	<p>The areas where cavitation occurs isn't changeable.</p> <p>Areas affected by cavitation are changeable.</p>
RI-2.06	<p>Velocity at the exit of the system exceeds 10 m/s.</p> <p>Change 2.06. Talking about velocity in water filled pipes, not at exit. This limit is not exceeded.</p>
RI-2.07	<p>The system isn't satisfactory when it comes to mechanical strength.</p> <p>The mechanical strength of the system is suitable for its purpose.</p>
RI-2.08	<p>The system is not in compliance with the guidelines from NVE.</p> <p>Guidelines set by NVE has been followed.</p>
RI-2.09	<p>The system does not pass basic safety standards.</p> <p>No immediate dangers produced by the system. Open gear solutions = should be covered.</p>
RI-2.10	<p>The system is not scalable.</p> <p>The system can be scaled down without problem. Scaling it up will require design changes or further reinforcements.</p>
RI-2.13	<p>The system costs more to produce than existing systems.</p> <p>Currently the system is equally or more expensive than existing systems. The system has not been optimized fully yet.</p>

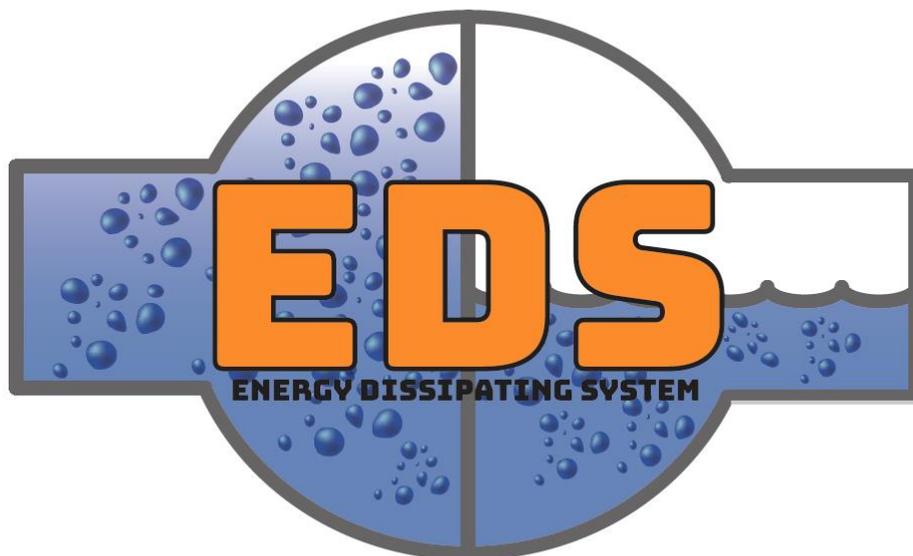
RI-2.14	<p>The system cannot be controlled from a remote location.</p> <p>The system has been equipped with actuators, making it possible to control from a remote location.</p>
RI-2.15	<p>Analyses are inaccurate.</p> <p>After multiple concerns from Multiconsult, there are still some uncertainties regarding some of the analyses.</p>
RI-2.16	<p>Poor design choices.</p> <p>There have certainly been some poor design choices. But because the group choose to use an incremental approach, these choices has been altered.</p>

Multiconsult

Design of bypass valve

Appendix D: Iteration document

22.05.2018



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MARKUS HJELLSETH	EXTERNAL SUPERVISOR: BJARNE BØRRESEN
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Abstract

Background: The project model is an iterative model and will thus contain a set of iterations. These iteration is review in this document.

Method: Each iteration will have its own objective and milestones. After a ended iteration the period will be evaluated.

Document history

Version	Date	Author	Description
0.01	10.01.18	OO	<ul style="list-style-type: none">• Making the document
0.02	12.01.18	OO	<ul style="list-style-type: none">• Introduction• Iteration I1
0.03	15.01.18	OO	<ul style="list-style-type: none">• Iteration E1
0.04	26.01.18	OO	<ul style="list-style-type: none">• Iteration E2
0.05	07.02.18	OO	<ul style="list-style-type: none">• Iteration C1• Iteration review on E2
0.06	26.02.18	OO	<ul style="list-style-type: none">• Iteration C2• Iteration review on C1
0.07	23.03.18	OO	<ul style="list-style-type: none">• Iteration review on C2
0.08	19.05.18	JS, MH	<ul style="list-style-type: none">• Proofread
1.00	20.05.18	LH	<ul style="list-style-type: none">• Added abstract• Proofread

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1 Iteration plan

As mentioned in the project plan (see *Project Plan*) the group have divided the projects phases into iterations. Every iteration can be seen as a mini-project that is a part of the phase. In this document, the group will list down all the iteration report. One page is dedicated to each iteration. An iteration contains objectives, milestones and a review of the iteration. When an iteration meeting is being held the iteration plan and activity plan will be revised This will give us an overview of what the focus is on the current iteration. Further some high-level objectives will be set. Then a risk assessment will be done by looking at which objectives are important or must be done first. The objectives will be priorities with the letters A, B and C, where A is the most important.

Underneath is an overview of how the group initially have divided the iterations throughout the project.

January	February	March	April	May	June
1	1	1	1	1	1
2	2	2	2	2	2
3	E2	C2	I1	C4	T1
4					
5					
6					
7					
8					
9	C1	C3	C3	T1	I1
10					
11					
12					
13					
14					
15	E1	C3	C4	T1	I1
16					
17					
18					
19					
20					
21					
22					
23					
24					
25	E2	C4	C4	T1	I1
26					
27					
28					
29					
30					
31					

Table 50: Iteration plan



1.1 Updated iteration plan

Throughout the project there have been some changes to the iterations. These changes are mainly to the duration of each of them. Underneath is an updated iteration plan, which gives an overview over the current execution of the iterations. For more information about why these changes were made, go to the “iteration review” for the given iteration in the “iterations”-chapter.

January	February	March	April	May	June
1	1	1	1	1	1
2	2	2	2	2	2
3	E2	C2	C3.1	C3.2	T1
4					
5					
6					
7					
8					
9	C1	C2	C3.1	T1	T1
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23	C1	C2	C3.1	T1	T1
24					
25					
26					
27					
28					
29					
30					
31					

Table 51: Updated iteration plan



2 Iterations

2.1 I1

Period: 03.01.18 – 14.01.18

Objective	Priority
Document template	C
Decide project model	A
Have a draft of the project plan	B
Create a document for: Iteration, requirements, test and risk analysis	C

Milestones:

- Meeting with internal supervisor 11.01.18

Iteration review

So far, the group feels that the progress is going according to the plan. Distribution of responsibilities was a little too early to decide. The reasons are that one of the group members has not yet participated in the project work due to an exam.

2.2 E1

Period: 15.01.18 – (~~25.01.18~~)26.01.18

Objective	Priority
Make changes to project plan after feedback from internal supervisor	B
Do research within requirements	B
Analyze requirements from Multiconsult	A
Plan website	C

Milestones:

- Meeting with internal supervisor ~~16.01.18~~ -> 18.01.18 and 23.01.18
- Meeting with external supervisor ~~25.01.18~~ -> 26.01.18

Iteration review

After the first meeting with our internal supervisor, we got some feedback on our project plan. The weekend was then used to improve and change this document. 23.01 the group had our second meeting, and the internal supervisor was overall satisfied with the changes. The project plan is now nearly complete.

We did also get requirements from external supervisor (17.01.18). These requirements were analyzed and written down in the requirements specification document. After the meeting with external supervisor, the group made some changes in the document.

2.3 E2

Period: 26.01.18 – 06.02.18

Objective	Priority
Complete project plan and requirements specification	A
Create and complete Test specification and test plan	A
Prepare for presentation	B
Complete website	C

Milestone:

- Presentation 06.01.18
- Deliver all relevant documentation to supervisors and sensors 02.02.18
- Meeting with internal supervisor 30.01.18
- Meeting with external supervisor 02.02.18

Iteration review

This iteration ended when the presentation was finished. If we have a look at the planned objectives for the iteration the group see that website still isn't complete. This will be an objective in the next iteration with a higher priority. The presentation went well, and the group feel that the explanation of the project is understandable. Till next time the group will try being a little bit more entertaining. At this point some high-level requirements for the system is described. But after working with the test specifications the group realized that some requirements had to be redefined in order to be testable. After the presentation the external supervisor advice to start brainstorming some concepts before diving into the research. This will be taken into consideration in the next iteration. Looking at the project plan, the group see that we are on track, apart from the website.

2.4 C1

Period: 07.02.18 – 25.02.18

Objective	Priority
Develop at least 4 concepts	A
Research within cavitation	A
Research within existing solutions and technologies	B
Research within production methods	C
Complete website	B
Read “Maskinforeskriften”	C

Milestones:

- Meeting with external supervisor 09.02.18, 16.02.18, 23.02.18
- Meeting with internal supervisor 23.02.18 if concepts are ready.

Iteration review

In this iteration, the focus have been on developing concepts and extending our knowledge. Looking at the objectives the plan was to develop at least four concepts. At this point, the group have ten developed concepts. The group should have concentrated more on creating technical documents. The research objectives have been done and the website is complete. The group also planned to read through the “Maskinforeskriften”, but we decided this was an objective that should come later in the project.

2.5 C2

Period: 26.02.18 – ~~12.03.18~~ 23.03.18

Objective	Priority
Redesign the selected concepts	A
Evaluate the concepts with the criteria's in the Pugh matrix <ul style="list-style-type: none"> • Cavitation • Complexity • Weight and size • Impact on surroundings • Production method • Flow regulation • Energy dissipating • Flow characteristic 	A
Gather all created concepts from the brainstorming into one document	C
Make a concept document	A
Prepare for the second presentation	B

Milestones:

- Deliver relevant documentation for the second presentation 09.03.18
- Second presentation 13.03.18

Iteration review

The most noticeable change to the iteration is the extension of the period. Analyzing the criteria took longer time than expected. In a meeting with Mutliconsult on 02.03.18, the time problem was addressed. The group concluded that the concept selection will have a huge impact on the outcome of the project, thus it will be reasonable to extend the iteration. By extending the time in C1, the C4 was cut down with the same amount of days. Initially the C4 was planned to last 19 days, but the group see now that it may be abbreviated without having major consequences. After the second presentation, the plan was to analyse the two remaining criteria, Energy dissipation and production method. As you can see, the energy dissipation criterion is now removed. When simulating the energy dissipation, the group found out that all the concepts was able to dissipate a desired amount of energy, but that the cavitation occurring is the interesting factor. After consulting with our external supervisor, we decided to remove energy dissipation criterion and instead add a new criterion, the flow characteristic. Simulations of the flow characteristic gave a more comparable result and the simulation itself was more convincing. The analyses of the other criteria have gone more or less smoothly.

2.6 C3.1

Period: ~~13.03.18-22.04.18~~ 23.03.18-22.04.18

Objective	Priority
Perform theoretical calculations and gather values from relevant standards in order to have some dimensions and information to base the design on	A
Optimization of the flow characteristic	A
Select materials for main components	A
Look at different ways to construct the concept	B
Proofread and correct documents from the concept phase	C

Iteration review

From the initial project plan, the C3 iteration was one whole iteration. When setting objectives, the group saw that the goals were too general and unspecific. The solution was to split the C3 into two sub-iterations, C3.1 and C3.2. The benefit of splitting C3 into two is to get more clear objectives to work towards. Looking at the first objective, where the goal was to gather some design choices and base dimensions before starting CAD-modelling, we can conclude that objective is fulfilled. Wall-thickness, some choices within sealing and end-connections have been decided. The flow simulation was planned to be finished in this iteration, but the group sees that this needs to be extended. The flow simulations are more complex than first estimated. Another objective was to select materials for some main components which also has been fulfilled. A specific alloy material has been selected for the valve body, and a material has been selected for the valve trim parts that will experience the highest erosion. Some different design solutions have also been presented. Proofreading of the documents from the concept phase has not yet been done. The last two weeks have been hectic and the group has not had time to do it.

2.7 C3.2

Period: ~~13.03.18 - 22.04.18~~ 23.04.18 - 06.05.18

Objective	Priority
Design a CAD-model of the concept with data from calculations, standards and flow optimization	A
Do FEM-analysis to check if the parts can withstand the given parameters	A
Select materials for rest of the components	B
Present a budget for the production cost of the concept	B
Optimize the “Movable part” using FEM-analysis	C

Iteration review

The high level objective for the iterating was to end up with a complete concept design. This goal is more or less completed. A complete CAD-model with 2D-drawings finalized, but there are still improvements to be considered. At this point, there is some difficulties concerning service friendliness and how the part will be assembled in a decent way. FEM-analyses checking if the part can withstand the given pressure are completed. Materials are also selected. An objective that is not completed is the budget for the production method. Finding the prices for materials, processing and labor cost proved to a harder task than expected. After consultation with our stakeholder, the group decided to skip the cost estimating and rather focusing on describing the production method better. Optimization of the movable part is not completed. This objective has a C priority and the group have not been able to allocate the time to do it.

2.8 C.4

Period:-07.05.18-13.05.18

Objective	Priority
Perform the test from the test specification and write a test report document	A
Finalize the technical document	A
Make a larger and a smaller part in order to test scalability	B
Optimize the movable part	C

Iteration review

When evaluating the iteration, we can start looking at the first objective. The goal was to write a test report which is now complete. Most of the test could be related to simulations done in the technical documents. Next objective with finalizing the technical documents is complete as well. The documents still need to be proofread one more time before delivery. The third objective concerning the scalability was changed. Initially the group planned to make a smaller and a larger system, but after conversation with our stakeholder we understood that this was not necessary. Instead of scaling the model, the pressure was scaled. The pressure classes that was used in the test was PN25 and PN64. Optimization of the movable part is still not done in this iteration, and will thus not be

2.9 T.1

Period: 13.05.18-06.05.18

Objective	Priority
Proofread and complete all documents that will be a part of the bachelor thesis	A
Make an updated risk document	B
Prepare for the final presentation	B

Milestones

- Delivery of the bachelor thesis: 22.05.18
- Presentation at Multiconsult: 05.06.18
- Final presentation 06.06.18

Iteration review

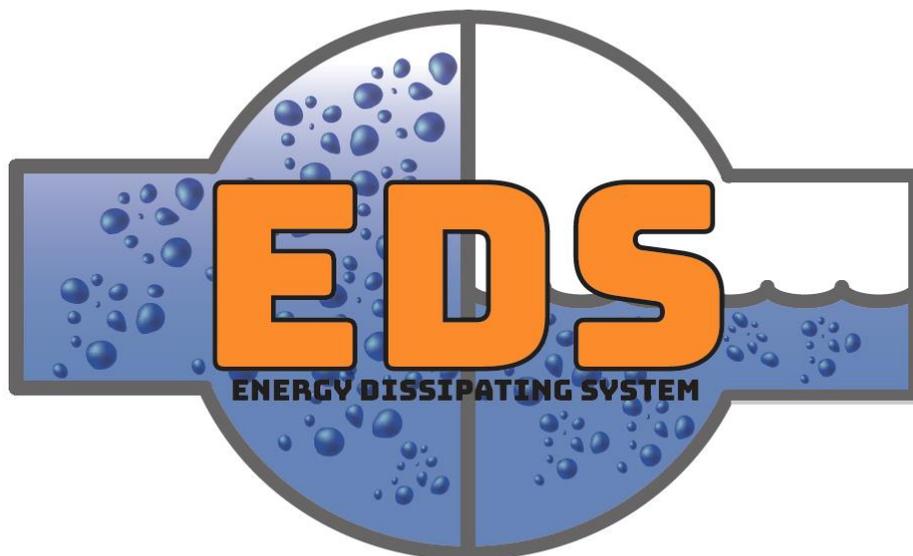


Multiconsult

Design of bypass valve

Appendix E: Concept gathering

22.05.2018



GROUPMEMBERS	SUPERVISORS
MARKUS HJELLSETH	EXTERNAL SUPERVISOR: BJARNE BØRRESEN
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Abstract

Background: For the design of the best possible system, the group has done several brainstorming sessions. This document collects all the concepts which came up in these sessions.

Method: For classifying the concepts, they have been separated into the three brainstorming sessions. And for explaining them, the group has used a card as a tool for giving a brief explanation of each concept. The card also shows the relationships between concepts and the treatment the group decided to apply the concept: Discarded, Stored for possible further use in another configuration or Further developed.

Document history

Version	Date	Author	Description
0.00	27.02.18	JS	<ul style="list-style-type: none">• Created the document
1.00	09.03.18	OO, MH	<ul style="list-style-type: none">• Proofread document
1.01	15.05.18	JS	<ul style="list-style-type: none">• Revised
2.00	19.05.18	JS	<ul style="list-style-type: none">• Added abstract• Proofread

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4	Concepts Gathering	355
4.1	First Brainstorm	355
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4.3	Third Brainstorm.....	374

1 Concept card

Concept ID	Previous concepts linked with	Concept Status
X.XX	Y.YY, Z.ZZ	Discarded, Stored for possible further use in another configuration or Further developed
Origin: where the ideas of the configuration and functioning come from to fulfil the requirements		
Description: Brief description on how the concept works		
Sketch: Simple sketch used to describe it during the brainstorming sessions		
Treatment and further development: use for any other concept, if applicable, or in a more detailed design		

- Concept ID (X.XX): X: Number of Brainstorm, XX: Number of Concept
- Code of colors for Status: **Discarded: "red"**, **Stored for possible further use in another configuration: "orange"** or **Further developed: "green"**.

2 Objective

The main goal of this analysis is to document the concepts which were formed during the concept development phase. This phase was divided into three brainstorming sessions, each with its own priorities. This document will give a better understanding of how the group narrowed down the number of concepts, which concepts were chosen and why they were chosen.

3 Results

Phase	Number of concepts			
	Total	Discarded	Stored for possible further using	Further developed
First Brainstorm	15	11	4	0
Second Brainstorm	21	10	10	1
Third Brainstorm	18	1	8	9
Total	54	22	22	10

Table 52: Number of concept of every type in each brainstorm

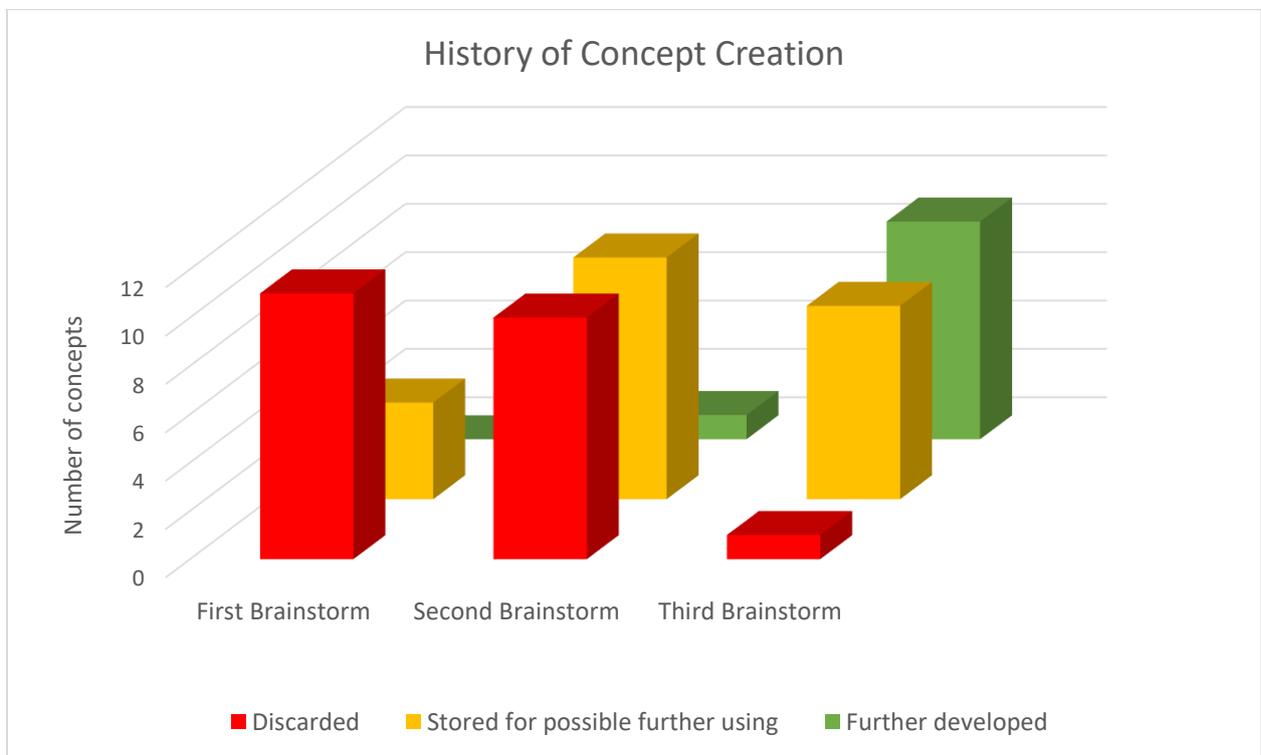
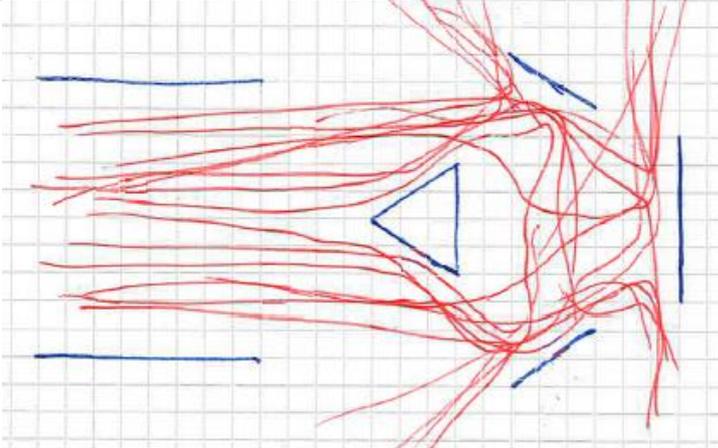
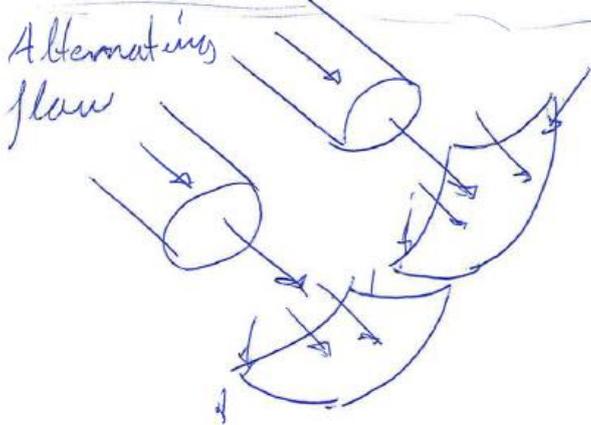


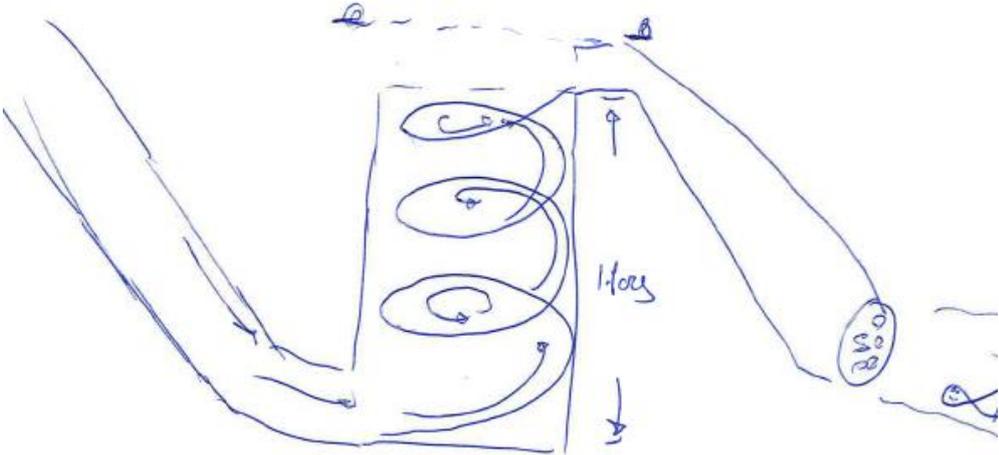
Figure 212: History of Concept Creation

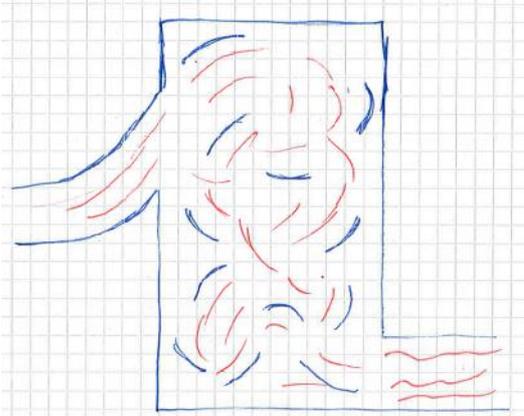
4 Concepts Gathering

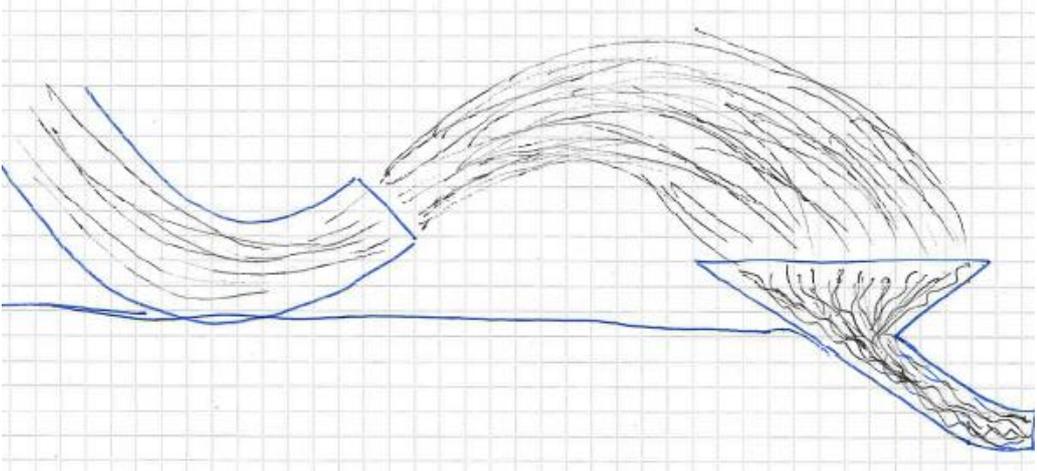
4.1 First Brainstorm

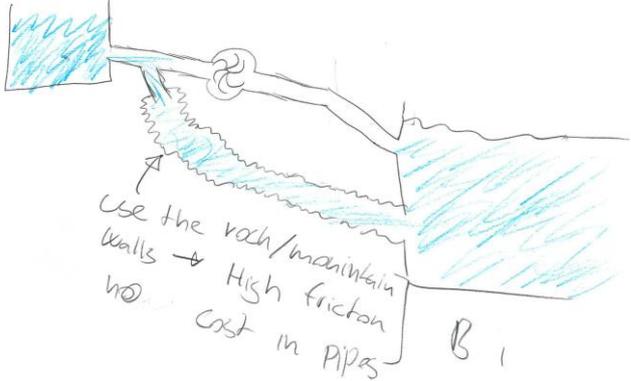
Concept ID	Previous concepts linked with	Concept Status
1.01	-	Stored for possible further use in another configuration
Origin: use the friction of objects and turbulence to dissipate the energy of the water		
Description: the system throws the water against a group of objects at high speed at the end of a pipe to split the water and produce friction against surfaces		
Sketch:		
		
Treatment and further development: As it doesn't regulate the flow it cannot be treated as a solution itself, but is stored for a possible further use as a combination with other ideas		

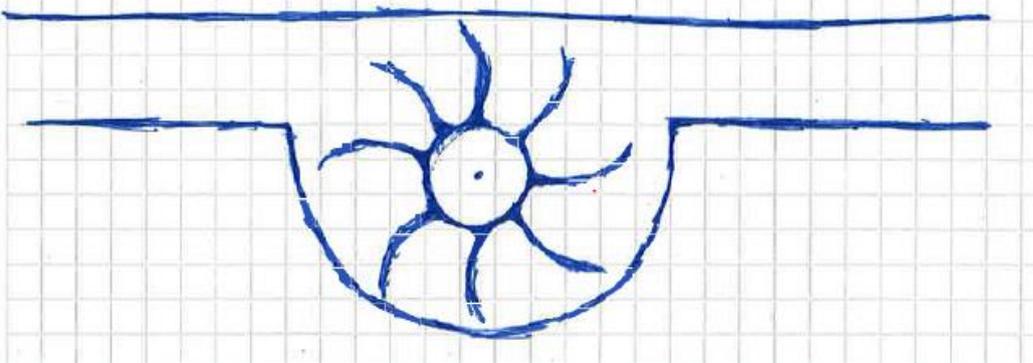
Concept ID	Previous concepts linked with	Concept Status
1.02	-	Discarded
Origin: use the friction of objects and turbulence to dissipate the energy of the water		
Description: the water is thrown against "parachutes" to create a high turbulence inside them, alternating between the "parachutes".		
Sketch:		
		
Treatment and further development: the concept is discarded due to it cannot regulate the flow and the poor efficiency		

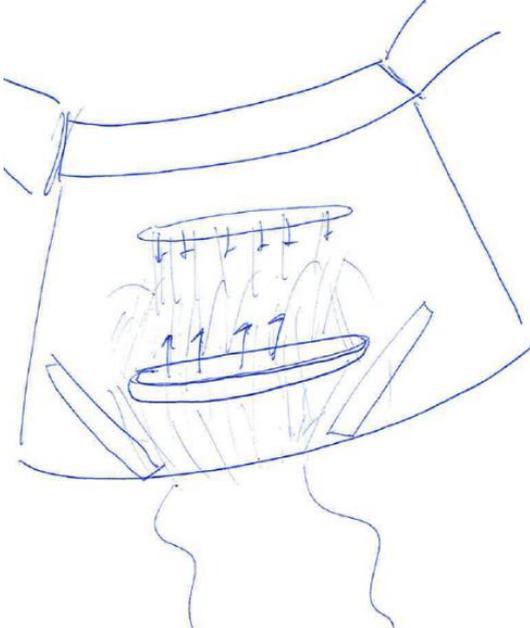
Concept ID	Previous concepts linked with	Concept Status
1.03	-	Stored for possible further use in another configuration
<p>Origin: use the friction of objects and turbulence to dissipate the energy of the water</p>		
<p>Description: The stream is connected to a tank where it losses energy by friction and turbulence</p>		
<p>Sketch:</p> 		
<p>Treatment and further development: use for any other concept if applicable or in a more detailed design</p>		

Concept ID	Previous concepts linked with	Concept Status
1.04	-	Discarded
<p>Origin: use the friction of objects and turbulence to dissipate the energy of the water</p>		
<p>Description: The stream is connected to a tank where it losses energy by friction and turbulence where it is guided by a group of deflectors inside the tank which increase the energy dissipation</p>		
<p>Sketch:</p> 		
<p>Treatment and further development: this concept has a similar functioning as other concepts but with a higher complexity, so it was decided to be discard</p>		

Concept ID	Previous concepts linked with	Concept Status
1.05	-	Discarded
Origin: mixing the stream with air to increase the turbulence		
Description: the stream of water is thrown up in the air and collected in a cone upon landing. The idea is that the air-resistance will dissipate energy.		
Sketch:		
		
Treatment and further development: the concept is too complicated and has a poor efficiency. Therefore, it is discarded		

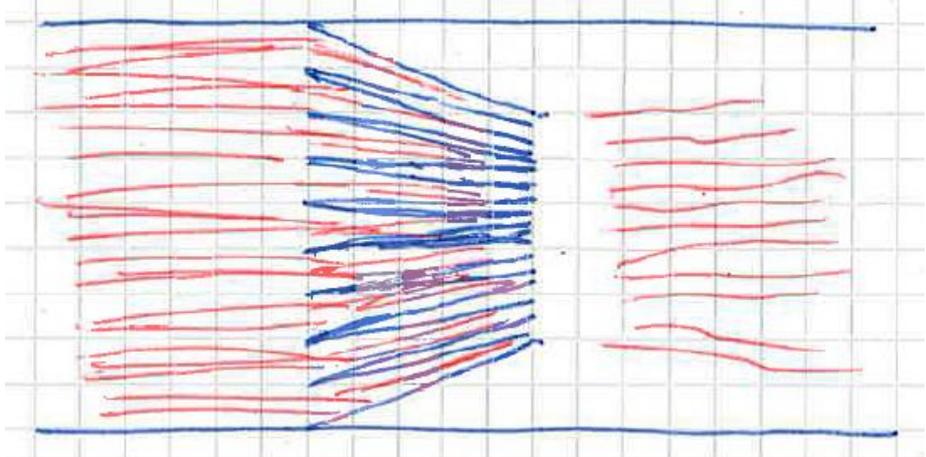
Concept ID	Previous concepts linked with	Concept Status
1.06	-	Stored for possible further use in another configuration
Origin: use the terrain as a cheap solution for the energy dissipation by friction		
Description: The bypass facility is a rough tunnel inside the ground which will dissipate the energy by friction and turbulence		
Sketch:		
		
Treatment and further development: the development of the concepts needs knowledge of geology, which none of the group has. And the flow cannot be regulated. As it is a cheap solution is stored for a possible further combination.		

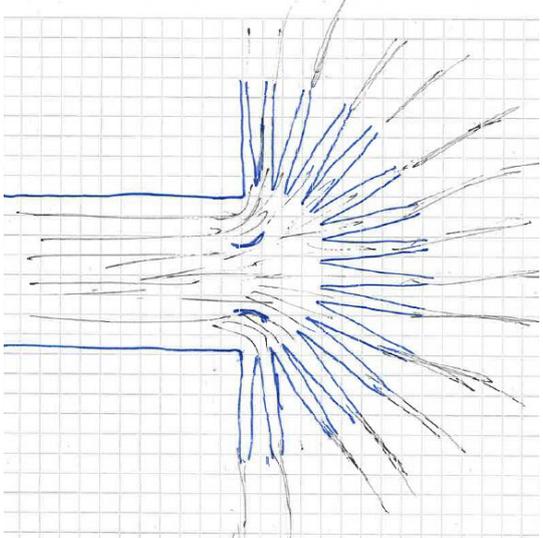
Concept ID	Previous concepts linked with	Concept Status
1.07	-	Discarded
Origin: Use a device to use extract the energy of the water		
Description: a turbine, different of the plant's, is used to extract the necessary energy of the water		
Sketch:		
		
Treatment and further development: the solution would work but the relation cost-efficiency is too low		

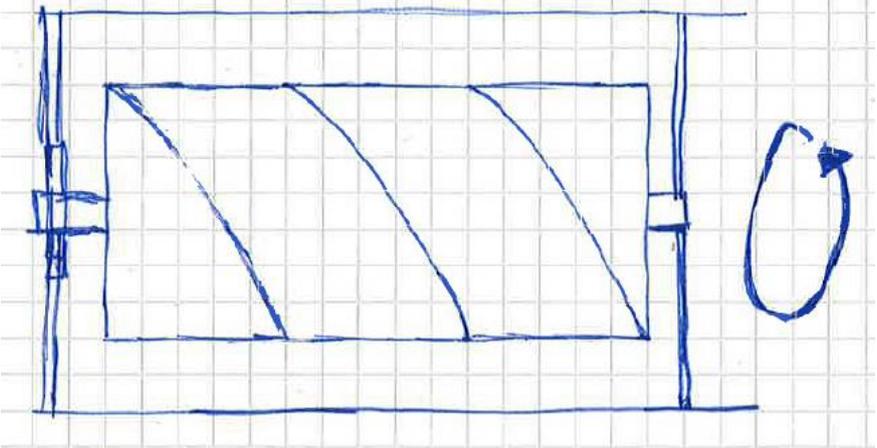
Concept ID	Previous concepts linked with	Concept Status
1.08	-	Discarded
Origin: use the friction with objects and turbulence to dissipate the energy of the water		
Description: the dry face of the dam is used as a surface to throw the water of the lower part of the reservoir, with a higher pressure, against the water of the upper part, with higher height. After it, the water will be conducted downstream.		
Sketch:		
		
Treatment and further development: the expensive construction of this concept and the possible poor efficiency resulted in discard it.		

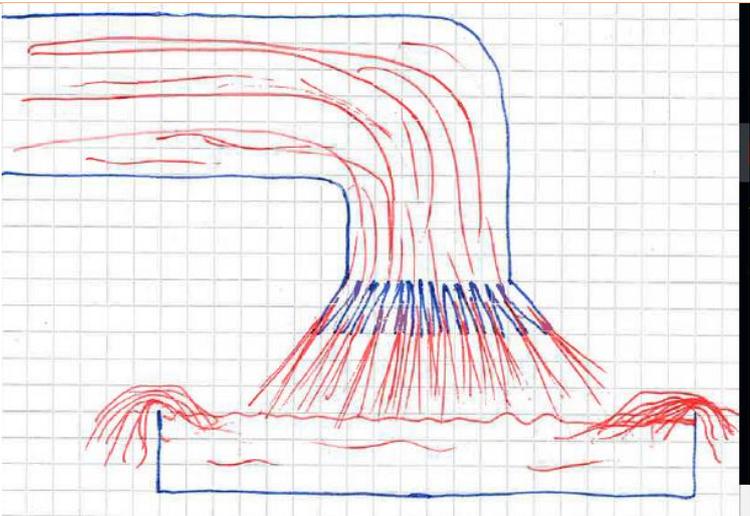
Concept ID	Previous concepts linked with	Concept Status
1.09	-	Discarded
Origin: use the friction with objects and turbulence to dissipate the energy of the water		
Description: the dry face of the dam is used as a surface to make the water pass through a series of objects with high speed		
Sketch:		
Treatment and further development: the expensive construction of this concept and the possible poor efficiency resulted in discard it.		

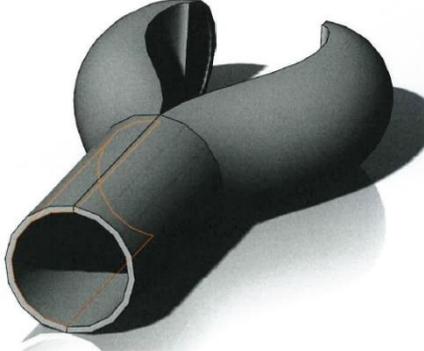
Concept ID	Previous concepts linked with	Concept Status
1.10	-	Discarded
Origin: increase the speed of the water to increase turbulence and friction		
Description: use a nozzle to increase the speed of the water inside the following pipe		
Sketch:		
Treatment and further development: the concept is discarded because of the great reaction forces and the poor efficiency		

Concept ID	Previous concepts linked with	Concept Status
1.11	-	Discarded
Origin: increase the speed of the water to increase turbulence and friction		
Description: use a series of small nozzles to increase the speed of the water inside the following pipe		
Sketch:		
		
Treatment and further development: the concept is discarded because of the great reaction forces and the poor efficiency		

Concept ID	Previous concepts linked with	Concept Status
1.12	-	Discarded
Origin: increase the speed of the water to increase turbulence and friction		
Description: use a series of small nozzles to increase the speed of the water to crash against a wall		
Sketch:		
		
Treatment and further development: the concept is discarded because of the great reaction forces and the poor efficiency		

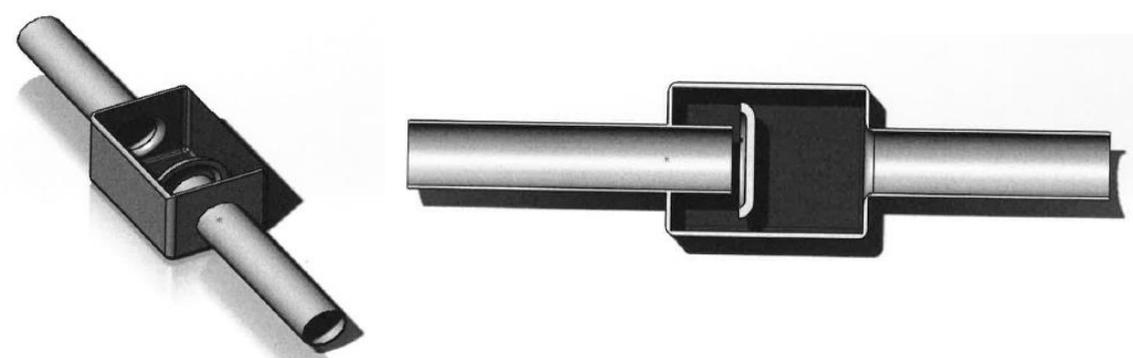
Concept ID	Previous concepts linked with	Concept Status
1.13	-	Discarded
Origin: use a device to regulate the friction and turbulence in the stream		
Description: Use a spinning helix with the axis in the direction of the water stream supported on breaks on the ends as a regulation device. The force on the breaks regulates the rate flow of the stream.		
Sketch:		
Treatment and further development: The device presents too much complexity and poor efficiency, so it is discarded		

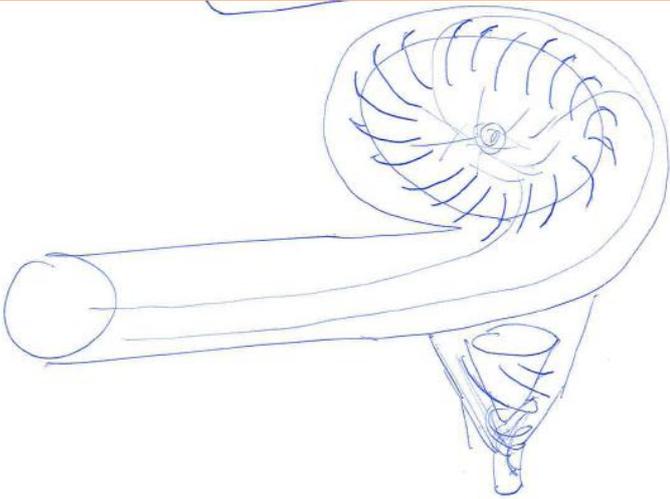
Concept ID	Previous concepts linked with	Concept Status
1.14	-	Discarded
Origin: increase the speed of the water to increase turbulence and friction in a tank		
Description: use a series of small nozzles to increase the speed of the water inside a following tank		
Sketch:		
Treatment and further development: the concept is discarded because of the great reaction forces and the poor efficiency		

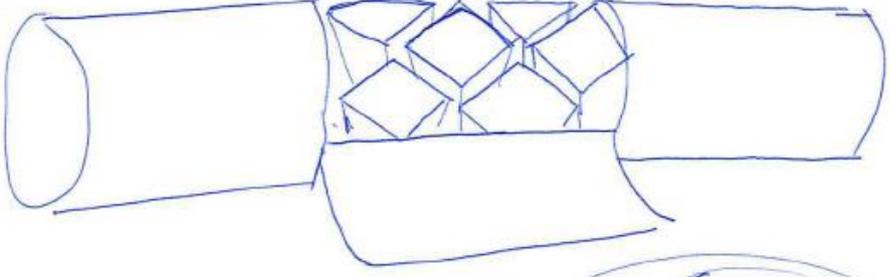
Concept ID	Previous concepts linked with	Concept Status
1.15	-	Stored for possible further use in another configuration
Origin: crash the water against itself to increase turbulence		
Description: The stream of water is spread out in two pipes and jet against itself downstream connecting again the two pipes		
Sketch:		
		
Treatment and further development: As it does not provide flow regulation it cannot be considered as a concept itself, but the mechanism of dissipation is stored for possible further development		

4.2 Second Brainstorm

Concept ID	Previous concepts linked with	Concept Status
2.01	-	Further developed
Origin: try to improve an existing solution		
Description: Two discs in contact with holes perpendicular to the stream direction. They change, by the rotation of one of them, the coincidence of the holes to regulate the flow and create a drop of pressure.		
Sketches:		
		
Treatment and further development: The concept fulfil all the requirements, so it is stored for a further development		

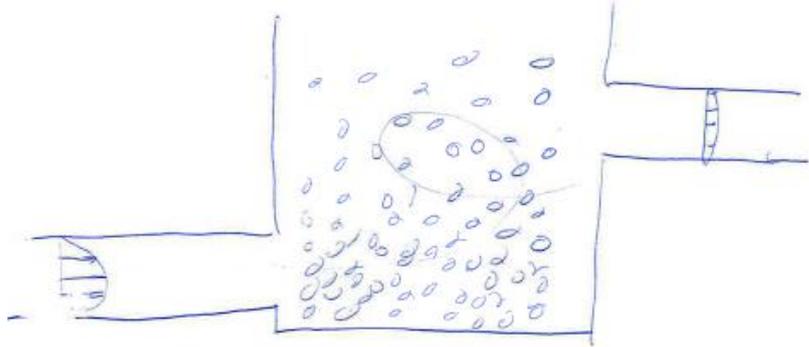
Concept ID	Previous concepts linked with	Concept Status
2.02	1.01	Stored for possible further use in another configuration
Origin: Jet the water against a tank with objects to increase the turbulence and the friction		
Description: The pipe ends in front of a wall, where the water crashes, which is contained into a tank with another pipe as a stream outlet		
Sketches:		
		
Treatment and further development: As it does not provide flow regulation it cannot be considered as a concept itself, but the mechanism of dissipation is stored for possible further development		

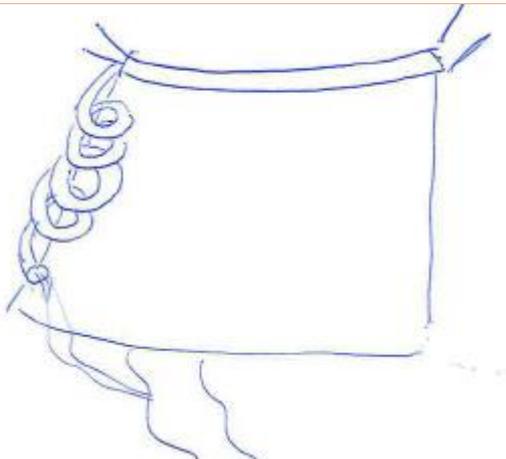
Concept ID	Previous concepts linked with	Concept Status
2.03	-	Discarded
Origin: Increase the speed of the water and jet it against itself		
Description: The pipe is connected to a cone with deflectors in spiral shape. These deflectors accelerate the water while it is conducted to the cone vertex where the crash occurs		
Sketches:		
		
Treatment and further development: As the geometry and the construction are too complex for the poor efficiency it would provide the group decided to discard it		

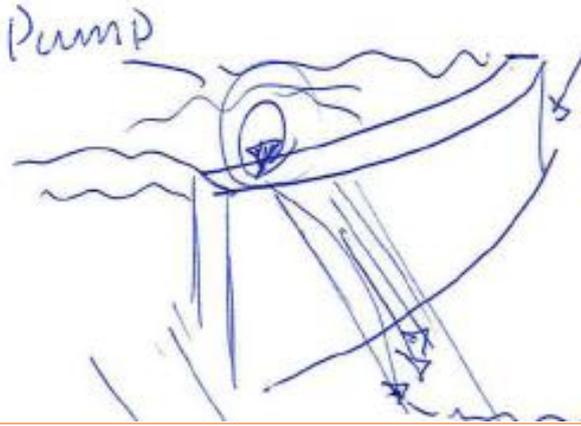
Concept ID	Previous concepts linked with	Concept Status
2.04	1.01 1.06	Discarded
Origin: increase the friction of the water against obstacles		
Description: inside an openable pipe there are some objects set around the axis of the pipe which increase the speed and the friction. The pipe is openable in order to facilitate the change of erased objects, which pyramid shaped.		
Sketches:		
		
Treatment and further development: The flow cannot be regulated, and the geometry is too complex for this purpose.		

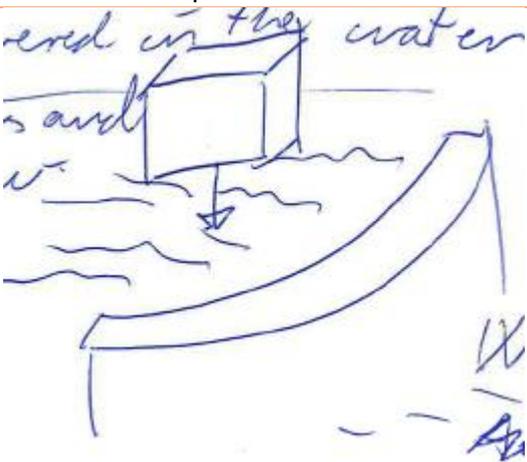
Concept ID	Previous concepts linked with	Concept Status
2.05	-	Stored for possible further use in another configuration
Origin: reduce the drop of pressure in the cavitation zone		
Description: a stream of air is connected to the water stream where the cavitation can occur. I cavitation occurs, the low pressure in this zone will suck out air which can reduce the drop of pressure in this zone.		
Sketches:		
Treatment and further development: The flow cannot be regulated, but the mechanism can be used for complementing any other concept		

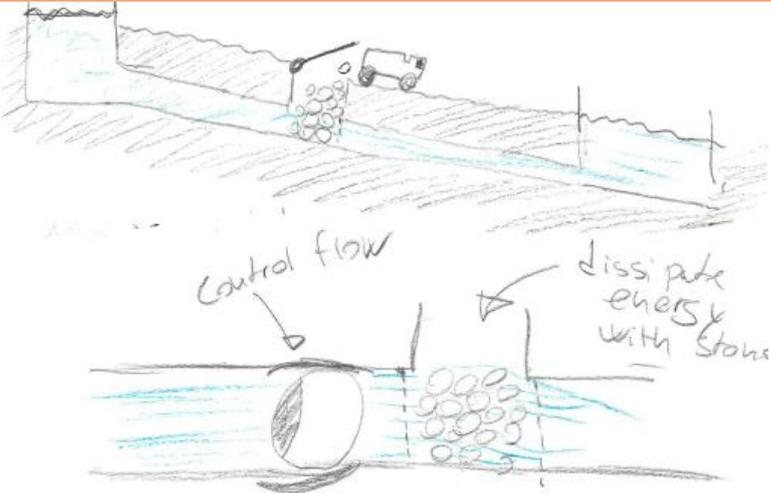
Concept ID	Previous concepts linked with	Concept Status
2.06	-	Discarded
Origin: Store the water at a lower height to use it when it is necessary		
Description: A small pipe will fill a big tank at the downstream river level. which has a bigger pipe with a valve which can be opened to give the required flow rate		
Sketch:		
Treatment and further development: This concept needs a valve to regulate he flow and needs time to be prepared for an emergency, so, it is discarded		

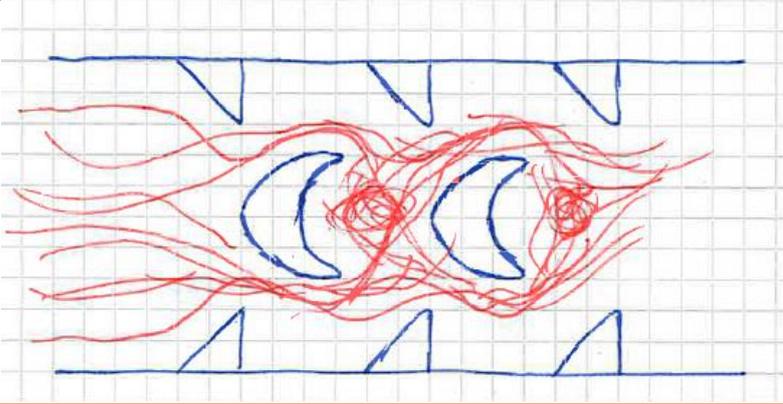
Concept ID	Previous concepts linked with	Concept Status
2.07	-	Discarded
Origin: use small particles to increase friction and turbulence		
Description: A tank with small particles receive the water with high speed and dissipates the energy by friction and turbulence inside		
Sketch:		
		
Treatment and further development: The friction this particle would cause in the tank and the downstream pipe make it a non-profitable concept		

Concept ID	Previous concepts linked with	Concept Status
2.08	-	Discarded
Origin: increase the velocity to increase friction		
Description: A long and narrow pipe goes along the dam to dissipate the potential energy		
Sketch:		
		
Treatment and further development: The size and poor efficiency makes it a poor concept. It is discarded		

Concept ID	Previous concepts linked with	Concept Status
2.09	-	Discarded
Origin: find an easy way for the water to go down		
Description: a pump will through the water above the dam		
Sketch:		
		
Treatment and further development: The efficiency is low and the cost too high to continue with the idea		

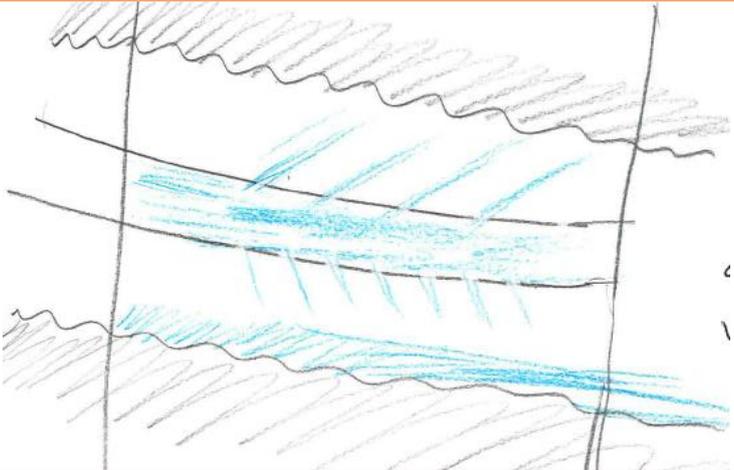
Concept ID	Previous concepts linked with	Concept Status
2.10	-	Discarded
Origin: find an easy way for the water to go down		
Description: a big object is thrown to the reservoir to make the level go over the maximum level of the dam and pass above it		
Sketch:		
		
Treatment and further development: The efficiency is too low and it can derivate in other problems for the dam		

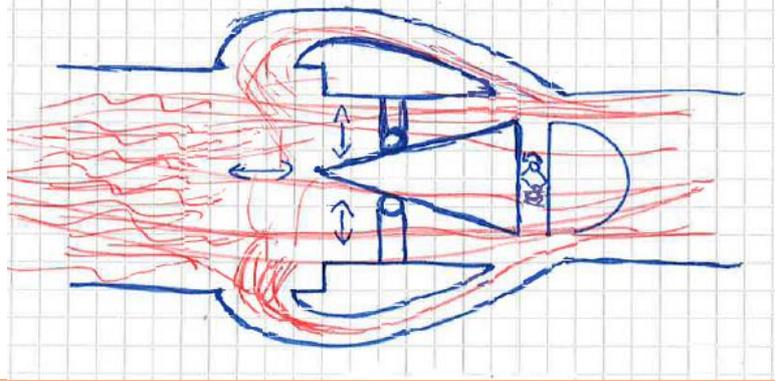
Concept ID	Previous concepts linked with	Concept Status
2.11	-	Stored for possible further use in another configuration
Origin: use objects to dissipate energy by friction		
Description: An openable part of the pipe is filled with rocks to increase friction		
Sketch:		
		
Treatment and further development: It cannot be treated as a solution itself, but it is a cheap solution for the energy dissipation. It is stored for combining with other flow regulating solutions		

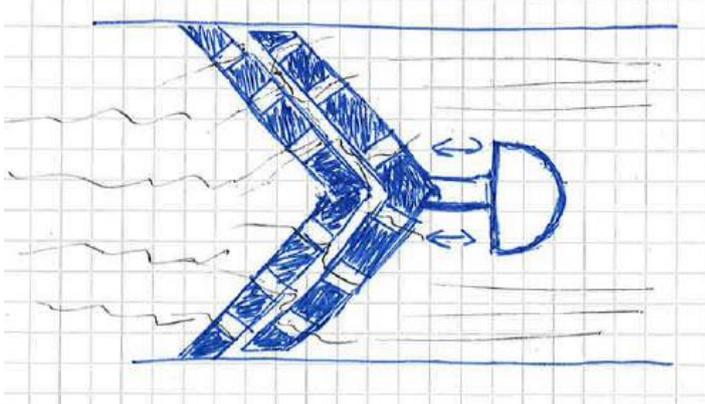
Concept ID	Previous concepts linked with	Concept Status
2.12	-	Discarded
Origin: use objects to dissipate energy by friction and design oriented to have cavitation far away from solid surfaces		
Description: The objects are made with a space in the downstream part to have the cavitation in it		
Sketch:		
		
Treatment and further development: The device cannot regulate the flow and its efficiency is low, so it is discarded		

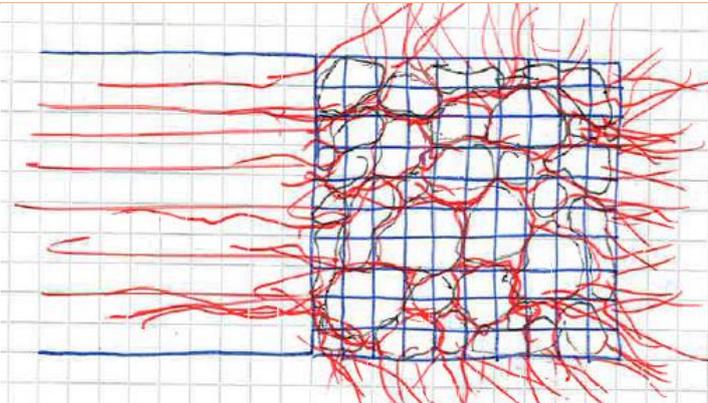
Concept ID	Previous concepts linked with	Concept Status
2.13	1.15	Stored for possible further use in another configuration
Origin: Jet the water against itself to increase turbulence		
Description: The stream of water is spread out in two pipes and crashed against itself downstream in a tank		
Sketch:		
Treatment and further development: As it does not provide flow regulation it cannot be considered as a concept itself, but the mechanism of energy dissipation is stored for possible further development		

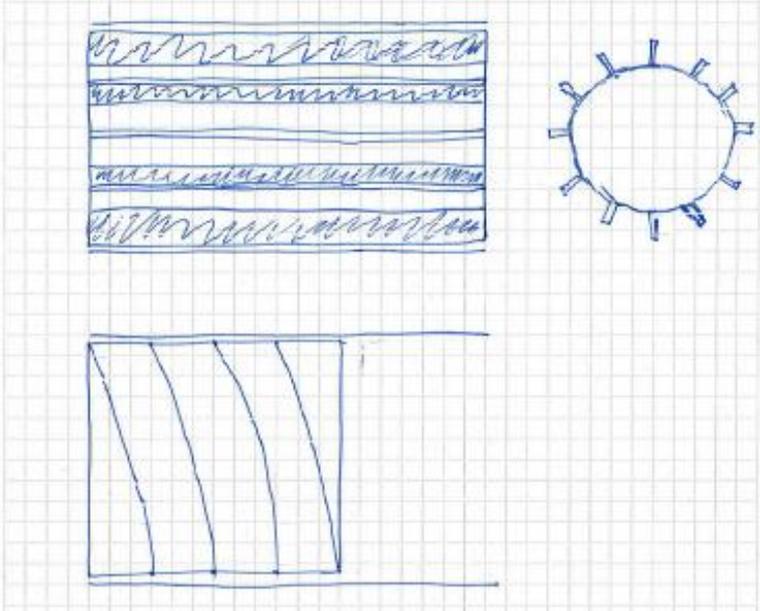
Concept ID	Previous concepts linked with	Concept Status
2.14	1.01 1.06 2.02	Stored for possible further use in another configuration
Origin: Crash the water against an object to increase friction and turbulence		
Description: the stream of water goes into a tunnel where it is jet against a wall inside the mountain and continues until the river		
Sketch:		
Treatment and further development: As it does not provide flow regulation it cannot be considered as a concept itself, but the mechanism of dissipation is stored for possible further development		

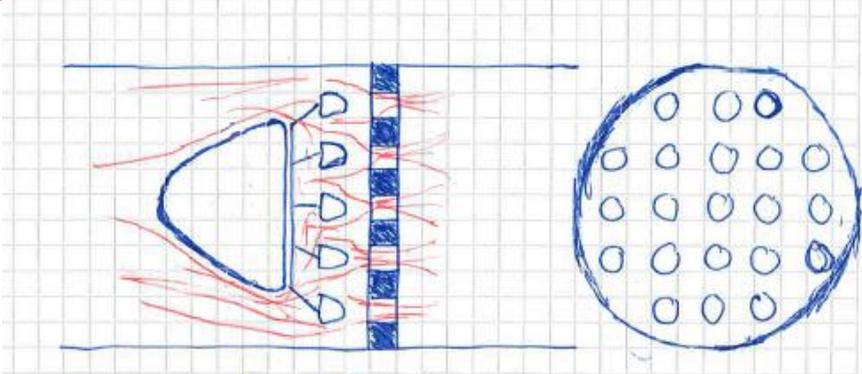
Concept ID	Previous concepts linked with	Concept Status
2.15	1.01.1.06 2.02	Discarded
Origin: Crash the water against an object to increase friction and turbulence		
Description: the pipe has several holes where the water comes out with high speed and crash against the wall of a tunnel		
Sketch:		
		
Treatment and further development: It does not provide flow regulation and it has an uncertain efficiency. It is discarded		

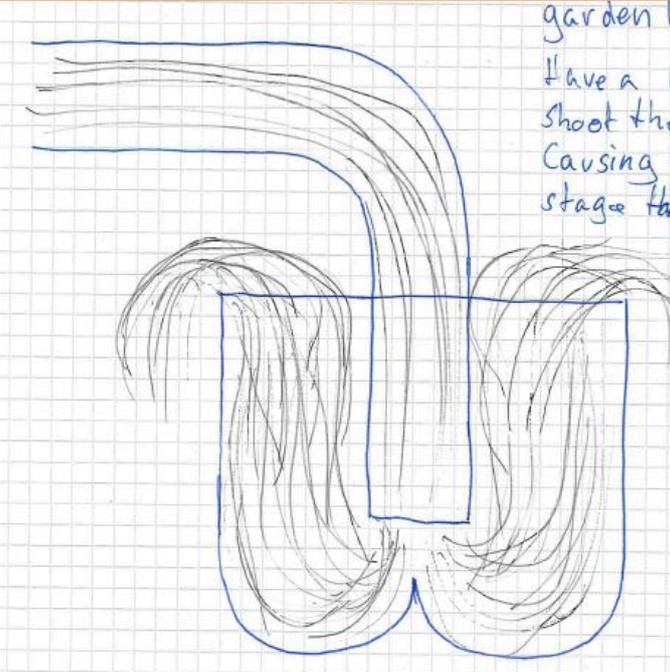
Concept ID	Previous concepts linked with	Concept Status
2.16	1.15	Stored for possible further use in another configuration
Origin: Crash the water against itself to increase turbulence		
Description: the inner object is divided in two parts which can regulate the flow changing the distances between them. After it, the water is divided a crashed against itself downstream.		
Sketch:		
		
Treatment and further development: The concept fulfil all the requirements, but it has a high complexity. It is stored for further simplification.		

Concept ID	Previous concepts linked with	Concept Status
2.17	-	Stored for possible further use in another configuration
Origin: Jet the water against itself to increase turbulence		
Description: two cones with holes are set concentrically in the pipe, so the distance between them regulates the flow rate. The water crashes against itself with a high velocity at the exit of the second cone.		
Sketch:		
		
Treatment and further development: The concept fulfil all the requirements, but it is not completely specified. It is stored for further development.		

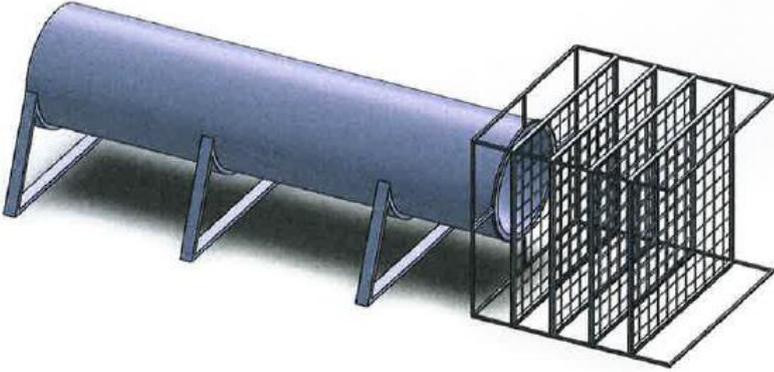
Concept ID	Previous concepts linked with	Concept Status
2.18	2.11	Stored for possible further use in another configuration
Origin: use objects to dissipate energy by friction		
Description: A part of the pipe, or at the end, is filled with rocks in metallic nets, making it easy to change the erased rocks		
Sketch:		
		
Treatment and further development: It cannot be treated as a solution itself, but it is a cheap solution for the energy dissipation. It is stored for combining with other flow regulating solutions		

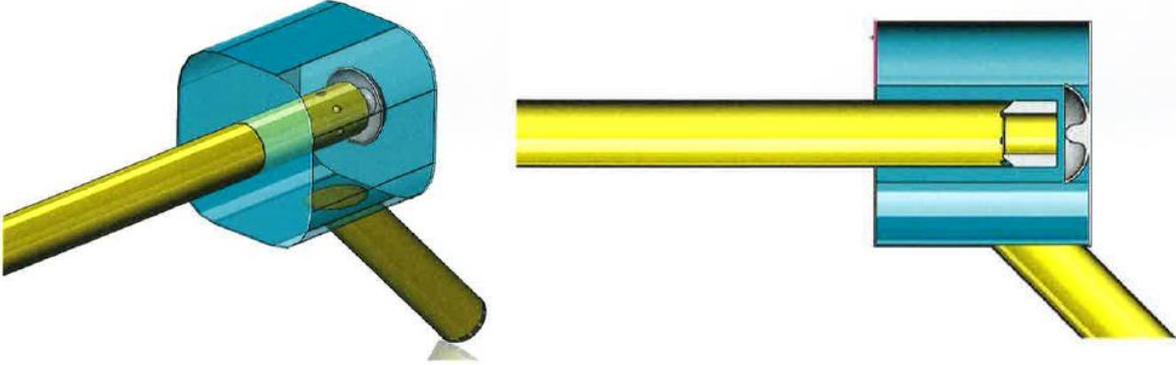
Concept ID	Previous concepts linked with	Concept Status
2.19	1.13	Discarded
Origin: Increase the path the water has to go through, to increase friction		
Description: Use a fix helix to make the water rotate while it is going downstream		
Sketch:		
		
Treatment and further development: The device presents too much complexity and poor efficiency, so it is discarded		

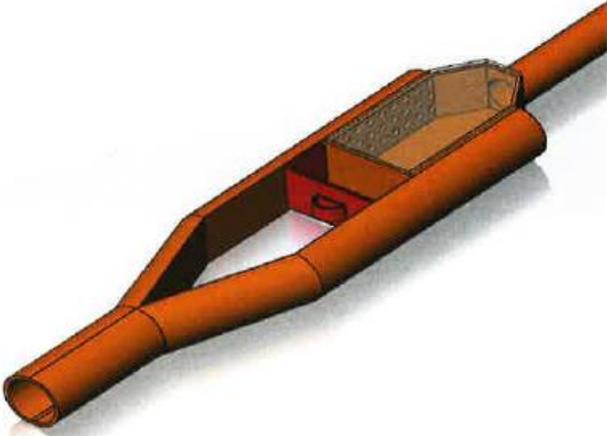
Concept ID	Previous concepts linked with	Concept Status
2.20	1.11 2.01 2.17	Stored for possible further use in another configuration
Origin: increase the speed of the water and crash it to increase friction		
Description: use a disc with holes to make the water go faster through it, a set objects behind these holes to jet the water against them		
Sketch:		
		
Treatment and further development: The device present a high complexity, but it solves all the requirements. It is stored for further development		

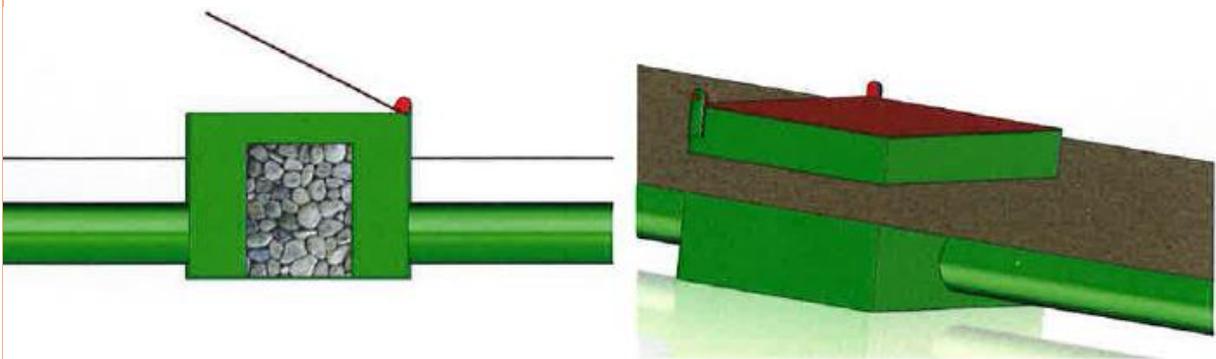
Concept ID	Previous concepts linked with	Concept Status
2.21	1.03 1.14	Stored for possible further use in another configuration
Origin: throw the water in a tank to increase turbulence		
Description: throw the water into a tank shaped to achieve the higher turbulence and friction possible		
Sketch:		
Treatment and further development: It cannot be treated as a solution itself, but it is a cheap solution for the energy dissipation. It is stored for combining with other flow regulating solutions		

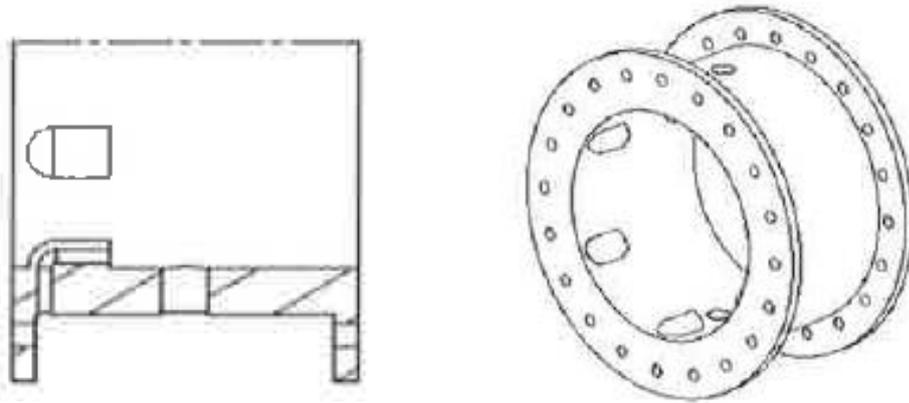
4.3 Third Brainstorm

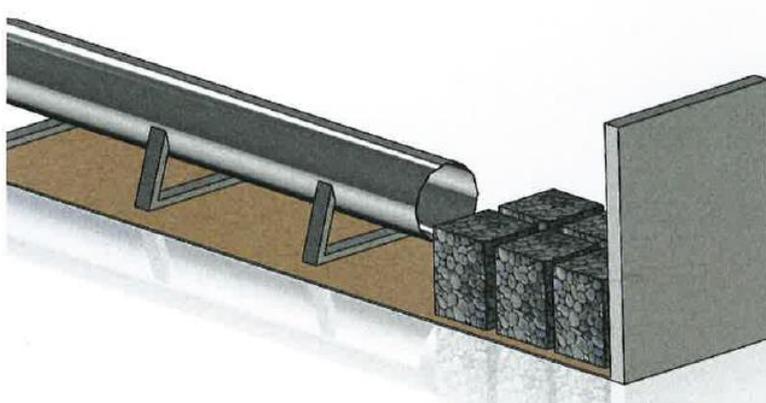
Concept ID	Previous concepts linked with	Concept Status
3.01	1.01	Stored for possible further use in another configuration
<p>Origin: crash the water against an object to increase friction and turbulence</p> <p>Description: the pipe ends in front a series of nets where the water crashes</p>		
<p>Sketch:</p> 		
<p>Treatment and further development: It cannot be treated as a solution itself, but it is a cheap solution for the energy dissipation. It is stored for combining with other flow regulating solutions</p>		

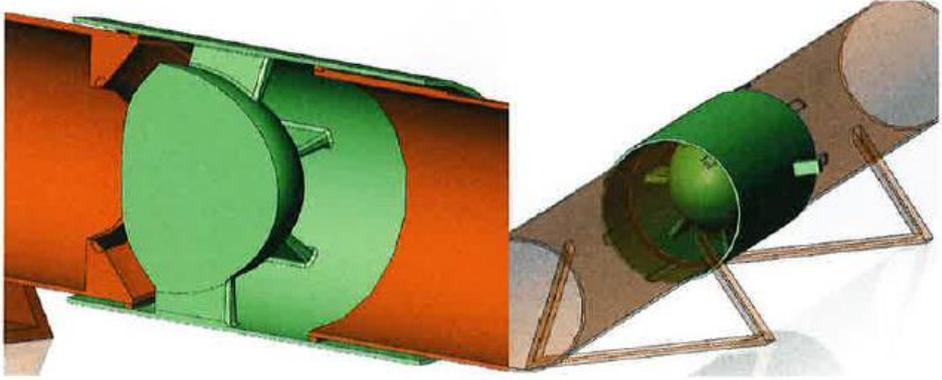
Concept ID	Previous concepts linked with	Concept Status
3.02	2.02	Stored for possible further use in another configuration
<p>Origin: jet the water against an object to increase friction and turbulence</p> <p>Description: The pipe ends inside a tank where it throws the water against a hole and through small holes in its wall. There is a smaller pipe inside the main pipe which regulate the flow changing the distance with the object.</p>		
<p>Sketch:</p> 		
<p>Treatment and further development: The concept solve all the problems but need to be simplified and improve. It is stored for possible further development</p>		

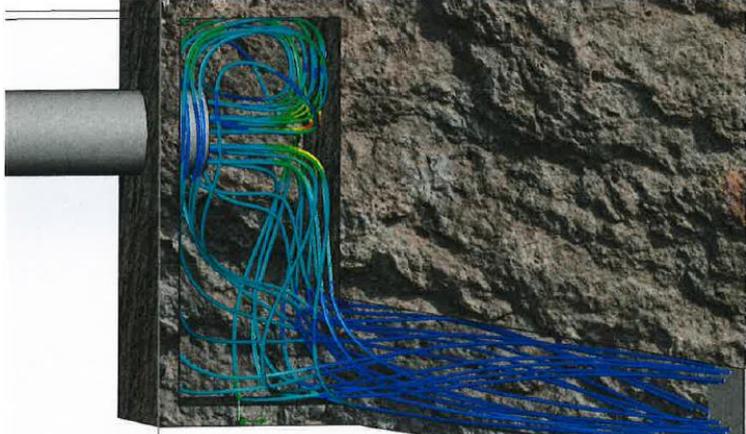
Concept ID	Previous concepts linked with	Concept Status
3.03	2.02	Further developed
<p>Origin: jet the water against itself to increase turbulence</p>		
<p>Description: The water is spread out in two pipes and thrown against itself in the box through several holes which connect the inlet pipes with the box. The flow is regulated with the red wall, which cover the number of holes required.</p>		
<p>Sketch:</p> 		
<p>Treatment and further development: The concept is simple, effective and regulable. It is decided to be further developed</p>		

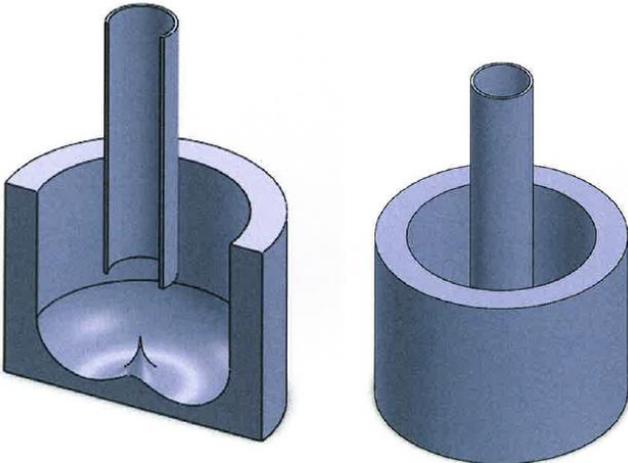
Concept ID	Previous concepts linked with	Concept Status
3.04	2.11	Stored for possible further use in another configuration
<p>Origin: Make the water go through some objects to increase friction</p>		
<p>Description: A part of the pipe is openable to be fulfilled with rocks and make the water go through it</p>		
<p>Sketch:</p> 		
<p>Treatment and further development: The concept is simple and cheap, but It cannot regulate the flow. It is stored for combining with other flow regulating solutions.</p>		

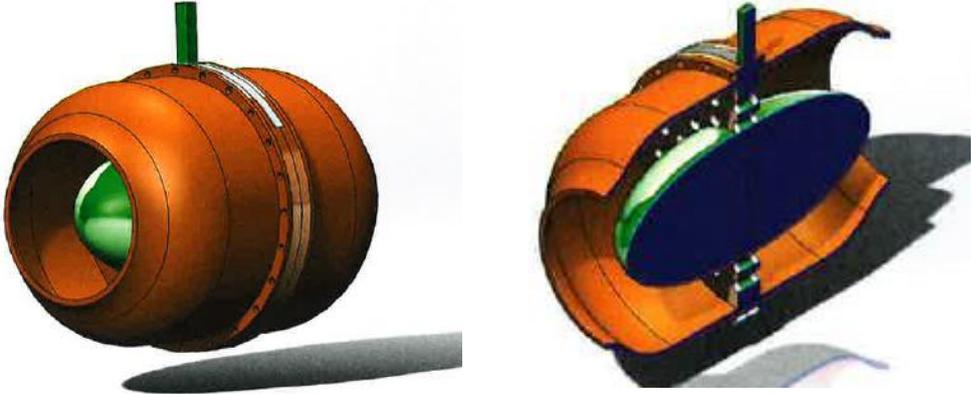
Concept ID	Previous concepts linked with	Concept Status
3.05	2.05	Stored for possible further use in another configuration
Origin: reduce the drop of pressure in the cavitation zone		
Description: The internal part of the pipe is connected to the exterior through some small tubes which are oriented towards the downstream zone, set inside an obstacle, to create a drop of pressure next to the wall inside the big pipe. The small tubes do not let the water to get out, and only let the air gets in with a high difference of pressure, coinciding when cavitation occurs, and avoiding it.		
Sketch: 		
Treatment and further development: This concept is an actual solution for the problem and does not regulate the flow or dissipate energy, so it is stored for possible combining with other solutions.		

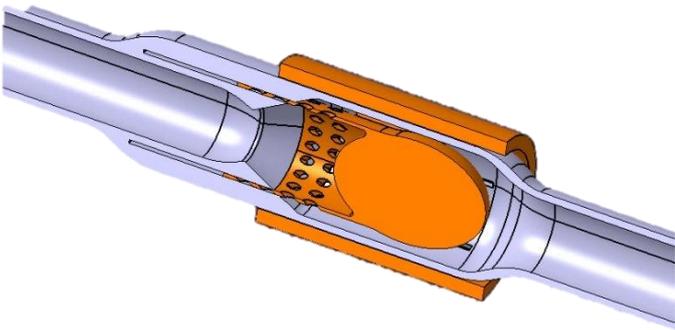
Concept ID	Previous concepts linked with	Concept Status
3.06	2.18	Stored for possible further use in another configuration
Origin: use objects to dissipate energy by friction		
Description: At the end of the pipe some packages of rocks are set to crash the water against them		
Sketch: 		
Treatment and further development: It cannot be treated as a solution itself, but it is a cheap solution for the energy dissipation. It is stored for combining with other flow regulating solutions		

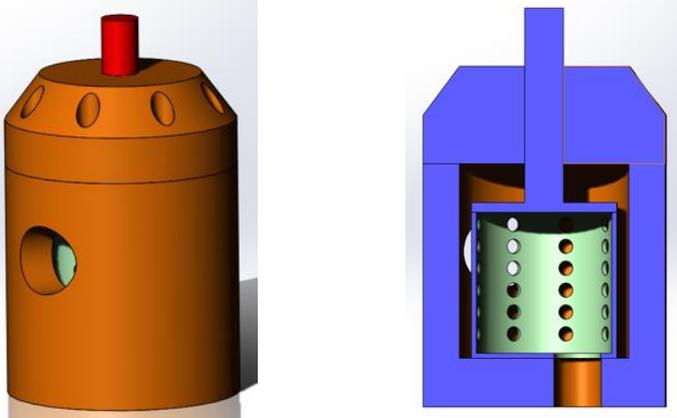
Concept ID	Previous concepts linked with	Concept Status
3.07	2.13 2.16	Stored for possible further use in another configuration
Origin: crash the water against itself to increase turbulence		
Description: The water is spread out around an object and jetted against itself at the end of this object with an axisymmetric deflector. The flow rate is regulated moving an external pipe with is connected to the object so the distance between the object and the deflector changes.		
Sketch:		
		
Treatment and further development: The concept is simple, effective and regulable, however, it will be improved to achieve better efficiency.		

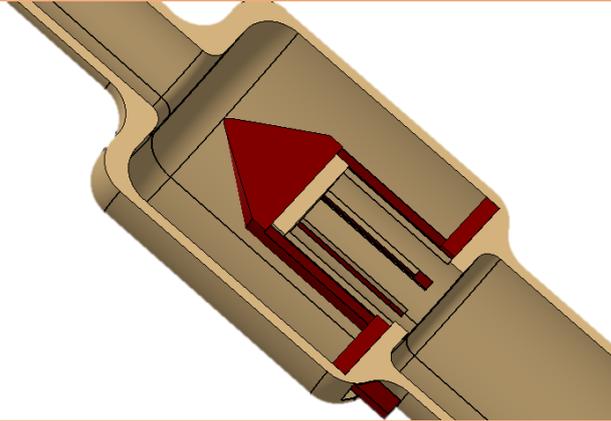
Concept ID	Previous concepts linked with	Concept Status
3.08	2.14	Discarded
Origin: crash the water against an object to increase friction and turbulence		
Description: the stream of water goes into a tunnel where it is crashed against a wall inside the mountain and continues until the river		
Sketch:		
		
Treatment and further development: As it does not provide flow regulation it cannot be considered as a concept itself and there are more efficient mechanisms for energy dissipation. It is discarded		

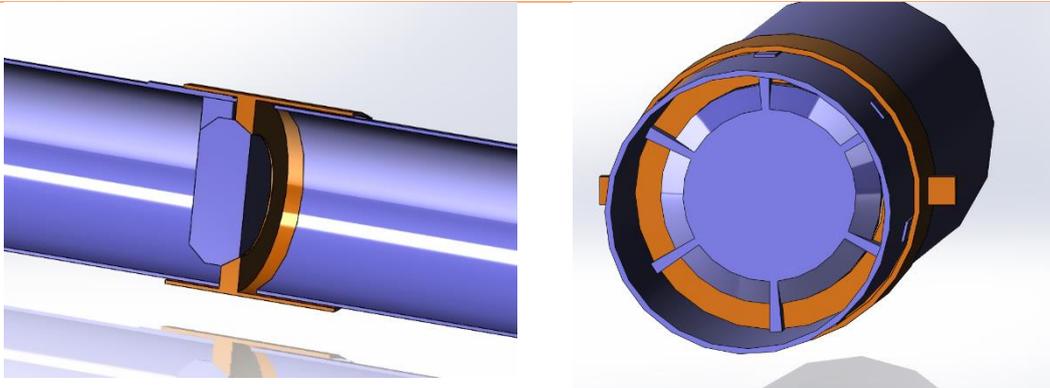
Concept ID	Previous concepts linked with	Concept Status
3.09	2.21	Stored for possible further use in another configuration
Origin: crash the water in a tank to increase turbulence		
Description: crash the water into a tank shaped to achieve the higher turbulence and friction possible		
Sketch:		
		
Treatment and further development: It cannot be treated as a solution itself, but it is a cheap solution for the energy dissipation. It is stored for combining with other flow regulating solutions.		

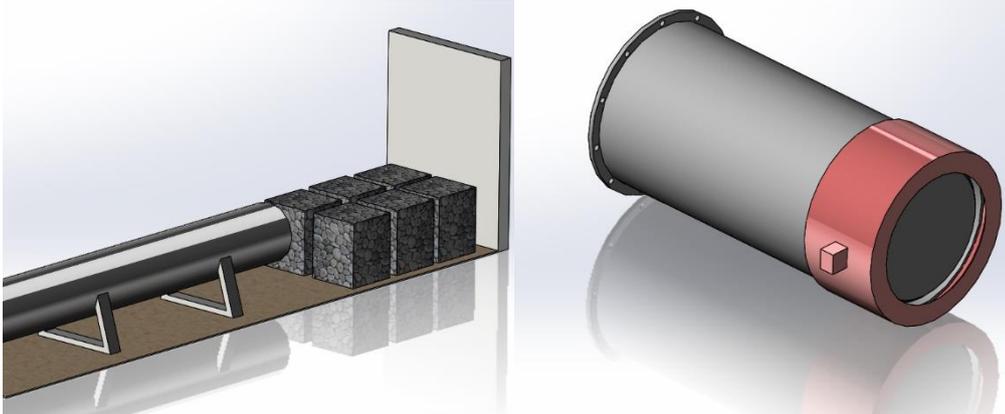
Concept ID	Previous concepts linked with	Concept Status
3.10	2.01	Further developed
Origin: crash the water against itself to increase turbulence		
Description: Two discs in contact with holes perpendicular to the stream direction change, by the rotation of one of them, the coincidence of the holes to regulate the flow and create a drop of pressure.		
Sketches:		
		
Treatment and further development: The concept fulfils all the requirements, so it is stored for a further development		

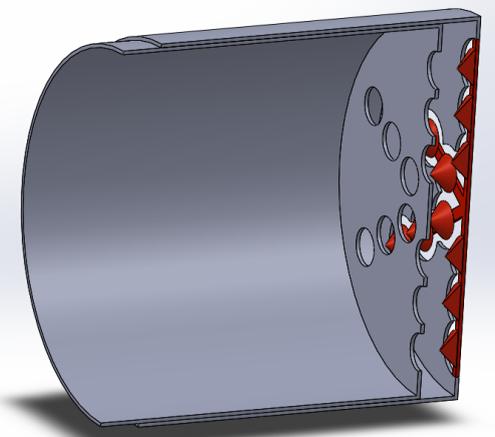
Concept ID	Previous concepts linked with	Concept Status
3.11	2.01 2.17 3.07	Further developed
Origin: crash the water against itself to increase turbulence		
Description: The water is spread out around an object and crashed against itself through several holes in the cylindrical continuation of the object. The flow rate is regulated moving an external pipe with is connected to change the number of holes covered.		
Sketch:		
		
Treatment and further development: The concept is simple, effective and regulable. It is decided to be further developed		

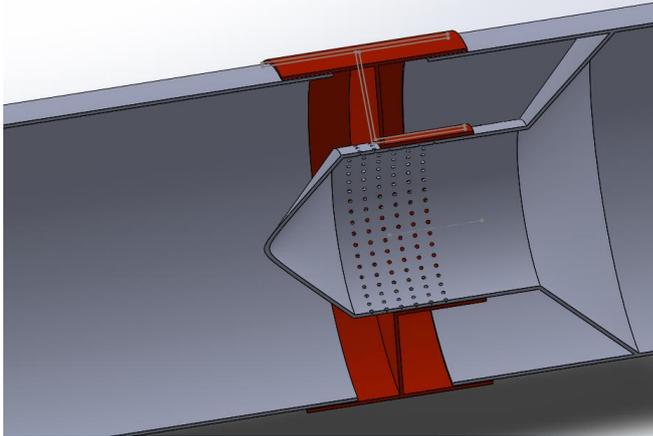
Concept ID	Previous concepts linked with	Concept Status
3.12	2.01 2.17 3.07	Stored for possible further use in another configuration
Origin: crash the water against itself to increase turbulence		
Description: The water enters in a cavity where it goes through several holes. In its axis the water crashes against itself and leave through a hole. The flow is regulated rotating the cylinder, because the cylinder has a hole which connects with the and the connected area changes while it is rotated.		
Sketch:		
		
Treatment and further development: Although the concept could work, it has a high size and complexity. It is stored for possible further using.		

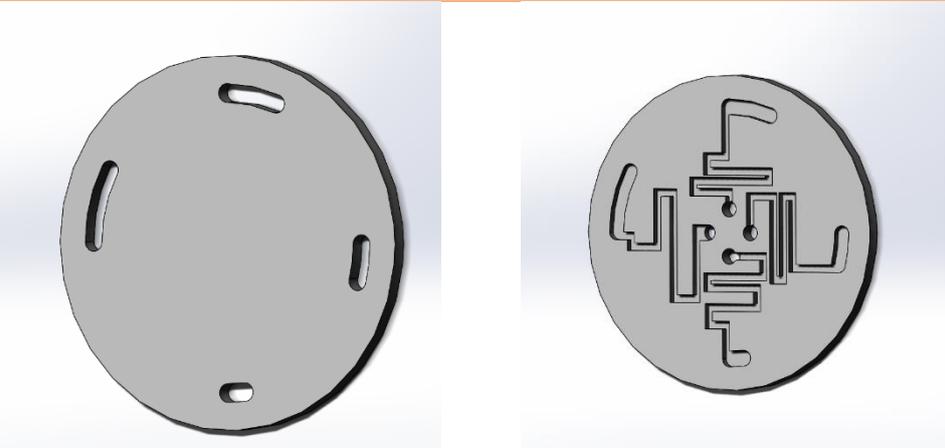
Concept ID	Previous concepts linked with	Concept Status
3.13	3.07 3.11	Further developed
Origin: crash the water against itself to increase turbulence		
Description: The water is spread out around a cone and crash through several objects inside a cylinder where it crashes in the axis. The flow is regulated rotating a concentric external cylinder which changes the number of holes covered.		
Sketch: 		
Treatment and further development: The concept is simple, effective and regulable. It is decided to be further developed		

Concept ID	Previous concepts linked with	Concept Status
3.14	3.07 2.13 2.16	Further developed
Origin: crash the water against itself to increase turbulence		
Description: The water is spread out around an object and crashed against itself at the end of this object with an axisymmetric deflector. The flow rate is regulated moving an external pipe with is connected to the object so the distance between the object and the deflectors changes.		
Sketch: 		
Treatment and further development: The concept is simple, effective and regulable. It is decided to be further developed		

Concept ID	Previous concepts linked with	Concept Status
3.15	3.13 3.07 3.06	Further developed
<p>Origin: crash the water against itself and against objects to increase turbulence and friction</p>		
<p>Description: The water is spread out around an object and crashed against itself at the end of this object with an axisymmetric deflector. The flow rate is regulated moving an external pipe with is connected to the object so the distance between the object and the deflectors changes. After this, the water crashes against rock packages.</p>		
<p>Sketch:</p> 		
<p>Treatment and further development: The concept is simple, effective and regulable. It is decided to be further developed</p>		

Concept ID	Previous concepts linked with	Concept Status
3.16	2.01	Further developed
<p>Origin: crash the water against itself to increase turbulence</p>		
<p>Description: A disc with holes which have a cone behind them to spread out the water and crashes against itself. Changing the distance between the object the flow is regulated.</p>		
<p>Sketches:</p> 		
<p>Treatment and further development: The concept fulfils all the requirements, so it is further developed.</p>		

Concept ID	Previous concepts linked with	Concept Status
3.17	3.07 3.11	Further developed
Origin: crash the water against itself to increase turbulence		
Description: The water is spread out around a cone and crashed through several objects inside a cylinder where it crashes in the axis. The flow is regulated moving an object which cover the number of holes required.		
Sketch:		
		
Treatment and further development: The concept is simple, effective and regulable. It is decided to be further developed		

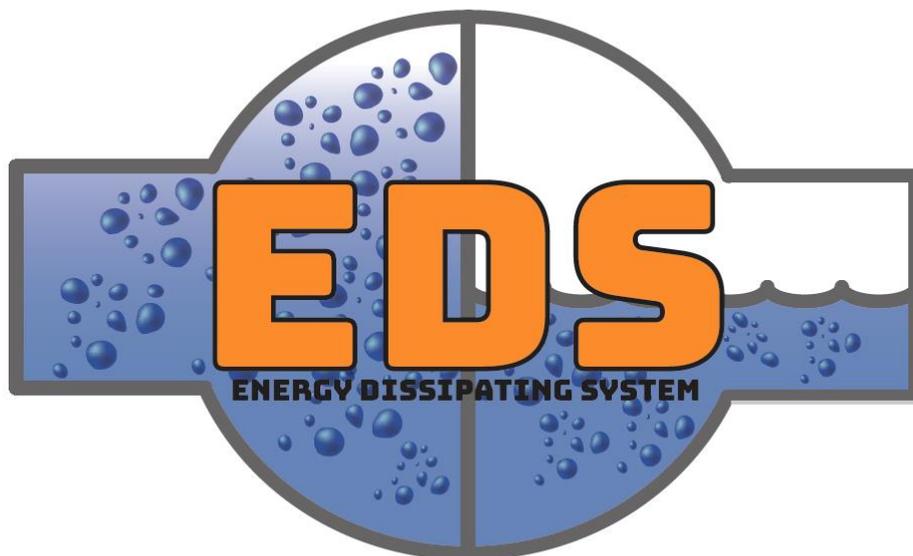
Concept ID	Previous concepts linked with	Concept Status
3.18	-	Further developed
Origin: make the water go faster to increase friction		
Description: Two parallel discs separate the water in the pipe. The first disc has holes which, depending on the relative position, let a determined rate flow pass to the next disc where it has to go through a maze drilled on the disc.		
Sketch:		
		
Treatment and further development: The concept is simple, effective and regulable. It is decided to be further developed		

Multiconsult

Design of bypass valve

Appendix F: Criterion analysis - weight & size

22.05.2018



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Abstract

Background: Weight & size and impact on surroundings are two of the criteria that will be compared in a Pugh-matrix to select the final concept.

Method: To evaluate the weight & size measurements, they will be taken from the CAD model and multiplied together to calculate the maximum volume for the model. This approximates how much space the valve would need once installed. The impact on surroundings criterion is evaluated based on how much physical space a concept requires once it is installed and whether it is installed, under or above ground. In both criteria the concepts will be rated on a scale from 1 to 6 where six is the best.

Results: Most of the concepts scored quite well in both criteria. The plug concept got a score of 6 which was the best. Moveable pipe 1 and 3 received a score of 5.5 in weight & size on a shared second place. The bucket concept scored the worst due to its huge size. In the impact on surroundings criterion the plug, maze, movable pipe 1 and 3 all received a score of 6. This is because they are mounted inline with the pipe and will not require any significant geological work to be installed. The two worst concepts in this criterion were the bucket and rock block which both are quite large.

The goal of this document is to analyze the two criteria: Weight & Size and Impact on surroundings. The ten concepts will be measured and scored from 1-6 in the two criteria.

Document history

Version	Date	Author	Description
0.01	02.03.2018	LH	<ul style="list-style-type: none">• Created the document• Preliminary analysis in Weight & Size
0.02	06.03.2018	LH	<ul style="list-style-type: none">• Impact on surroundings analysis• Deleted space usage and added it in impact
0.03	06.03.2018	LH	<ul style="list-style-type: none">• Added an updated Abstract• Rewrote Criterion description
0.04	07.03.2018	JS, OO	<ul style="list-style-type: none">• Proofreading
0.05	08.03.2018	LH, OO, MH, JS	<ul style="list-style-type: none">• Discussed the scores
1.00	08.03.2018	LH	<ul style="list-style-type: none">• Finalizing the document
2.00	17.05.2018	LH	<ul style="list-style-type: none">• Proofreading and some small corrections

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1 Criteria description

This document will analyze the ten concepts in two criteria: Weight & Size and Impact on Surroundings. Weight & Size is an important measurement for how practical a valve is. It can also give an idea of the cost of the valve. Impact on surroundings focuses mainly on the space usage of the valve once installed and the impact it will have on the immediate surroundings, since this will give an easily measurable and comparable value. In the following chapters the different concepts will be evaluated, compared and rated on a scale from 1-6.

1.1 Testing methodology

There are several steps that must be done before evaluating and scoring the concepts.

- Remove any part that is not a part of the valve. For example, pipes.
- Record **length, width and height** with the measurement tool on the model in SolidWorks. These values should be the maximum for the valve.
- Calculate the volume of the three measurements from step 2.
- Assess how much of the valve that consist of massive parts and how much of it that is free space.

1.2 Rating system

The concept will be rated in the matrix below and the final score for this criterion is the average score of the two. The two tables that are used are shown in Table 53 and Table 54.

Criteria	Score
Maximum volume	
Massiveness	
Total score	

Table 53: Weight & Size evaluation table

Criteria	Score
Impact on surroundings	

Table 54: Impact on surroundings evaluation table

1.3 Weight & Size

It is difficult to measure the weight of the valve in such an early stage since the material is not yet chosen. The weight aspect will therefore be covered in the massiveness score.

1.3.1 Maximum volume

Multiplying the height, weight and width of the maximum measurements.

1.3.2 Massiveness

Assess how much of the valve that consists of massive parts. More massive parts amounts to larger total weight and a lower score.

1.4 Impact on surroundings

Each concept will be evaluated based on its performance in this criterion, they will be rated from 1 to 6. The rating will be based on how much space the valve will use once it is installed. We will also evaluate where it will be installed.

2 Concept analysis

2.1 Concept-1 Bucket

This is the largest concept in term of size it requires.

2.1.1 Weight & Size

2.1.1.1 Maximum volume

Height:	4000 mm
Width:	8250 mm
Length:	8250 mm

Table 55: Maximum volume for Concept-1

$$V = h * l * w$$

$$V = 4000 * 8250^2$$

The volume is thus 272.25 m^3 which is very large. This amounts to a score of 1.

2.1.1.2 Massiveness

This concept is massive, although it can be modified to have more hollow space. Therefore, it will receive a score of 2 out of 6.

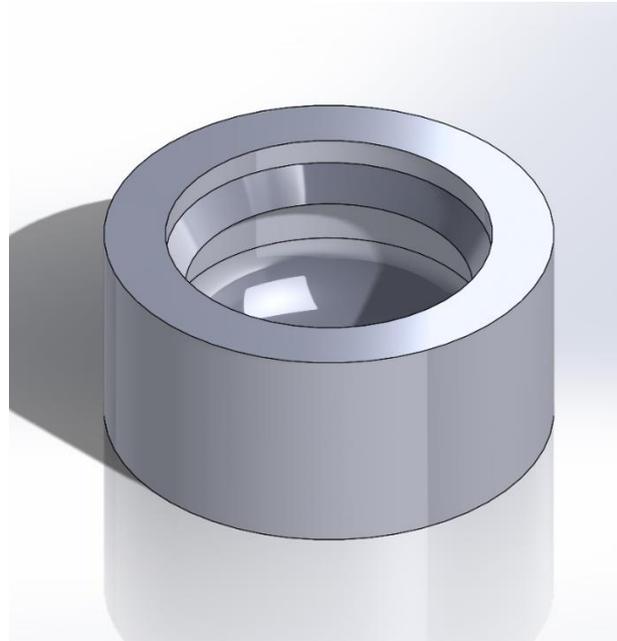


Figure 213: Bucket

Criteria	Score
Maximum volume	1
Massiveness	2
Total score	1.5

Table 56: Weight & Size evaluation for Concept-1

2.1.2 Impact on surroundings

Next is the impact on the surroundings. This valve uses much space when it is installed and would most likely require extensive geological work to make it fit underground. This also amount to the lowest score of 1.

Criteria	Score
Impact on surroundings	1

Table 57: Impact on the surroundings evaluation for Concept-1

2.2 Concept-2 Movable pipe-1

The movable pipe is a compact design where the valve is inside the pipe.

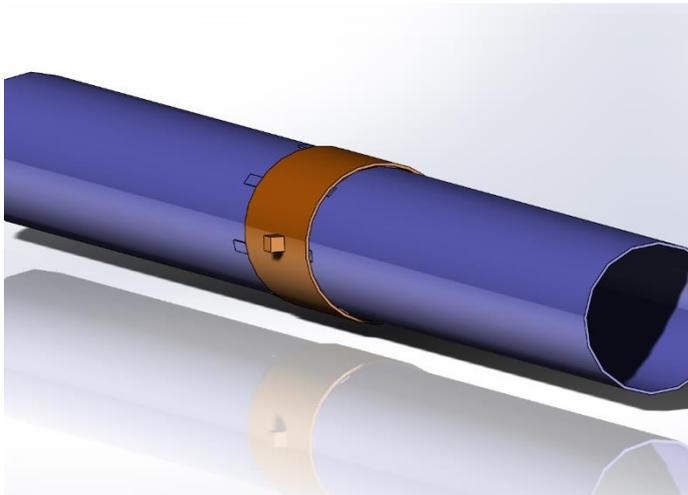


Figure 214: Movable pipe

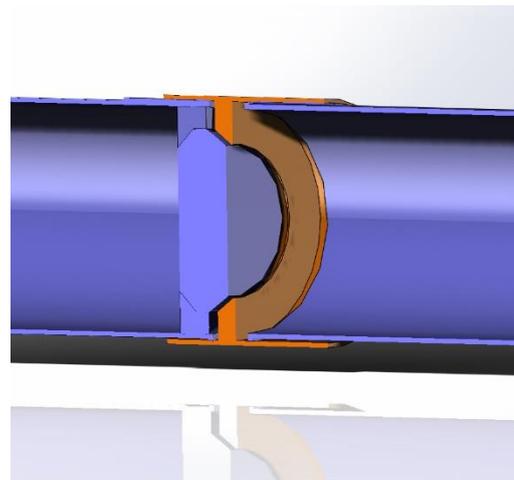


Figure 215: Cross section

2.2.1 Weight & Size

2.2.1.1 Maximum volume

Height:	1100 mm
Width:	1100 mm
Length:	1500 mm

Table 58: Maximum volume for Concept-2

$$V = h * l * w$$

$$V = 1500 * 1100^2 = 1.815 \text{ m}^3$$

The volume is 1.815 m^3 which is very compact. This amount to a score of 6.

2.2.1.2 Massiveness

Since the valve is small, the massiveness of it is also relatively small. It has some massive part, such as the flow control block inside the valve. This will amount to a score of 5.

Criteria	Score
Maximum volume	6
Massiveness	5
Total score	5.5

Table 59: Weight & Size evaluation for Concept-2

2.2.2 Impact on surroundings

The valve is very compact, and after installation it will not require much extra space apart from a control mechanism. It is easy to install underground and will not impact the environment in any significance. Score: 6.

Criteria	Score
Impact on surroundings	6

Table 60: Impact on the surroundings evaluation for Concept-2

2.3 Concept-3 Jet Valve

The jet valve is a semi compact design where the control mechanism is outside of the valve.

2.3.1 Weight & Size

2.3.1.1 Maximum volume

Height:	1700 mm
Width:	1700 mm
Length:	1933 mm

Table 61: Maximum volume for Concept-3

$$V = h * l * w$$

$$V = 1933 * 1700^2 = 5.59 m^3$$

This valve is not that compact, but it can most likely be modified to fit inside the pipe. This amount to a score of 5 for the current design.

2.3.1.2 Massiveness

The egg shape in the middle is the only big massive part. This amount to a score of 4.

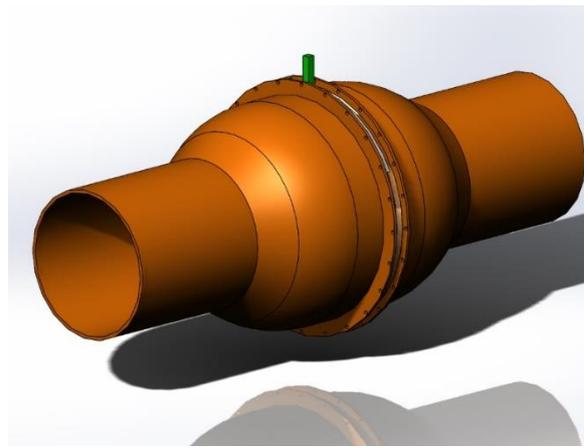


Figure 217: Jet valve

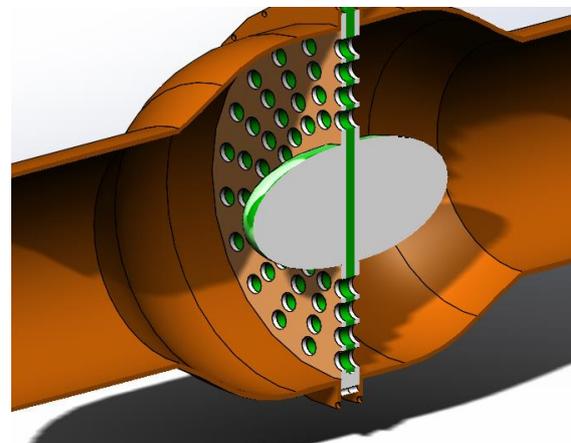


Figure 216: Cross section of jet valve

Criteria	Score
Maximum volume	5
Massiveness	4
Total score	4.5

Table 62: Weight & Size evaluation for Concept-3

2.3.2 Impact on surroundings

The valve body is larger than the pipe and is using more space, but not much. The control mechanism is also quite compact. The valve does not impact the environment in any significance.

Criteria	Score
Impact on surroundings	5

Table 63: Impact on the surroundings evaluation for Concept-3

2.4 Concept-4 Movable pipe-2

2.4.1 Weight & Size

2.4.1.1 Maximum volume

Height:	2200 mm
Width:	2200 mm
Length:	5800 mm

Table 64: Maximum volume for Concept-4

$$V = h * l * w$$

$$V = 5800 * 2200^2 = 28.07 \text{ m}^3$$

This valve is quite large and will receive a score of 3.

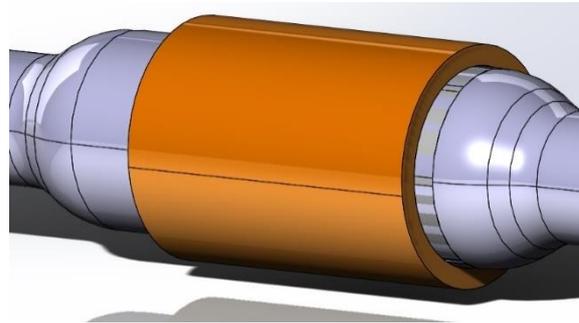


Figure 218: Movable pipe-2

2.4.1.2 Massiveness

The middle part is massive and will require some of the pipe to control where cavitation is occurring, so it will receive a score of 4.

Criteria	Score
Maximum volume	3
Massiveness	4
Total score	3.5

Table 65: Weight & Size evaluation for Concept-4

2.4.2 Impact on surroundings

The volume of the valve is quite high but as we can observe from *Figure 6* the valve is not particular big compared to the pipeline. The concepts do not require any large geological intervention and is versatile when it comes installation environment.

Criteria	Score
Impact on surroundings	4

Table 66: Impact on the surroundings evaluation for Concept-4

2.5 Concept-5 Energy dissipating box

The EDB is designed to have a good energy dissipation, and size was not a focus. The current version of the concept is not optimized in terms of space usage.

2.5.1 Weight & Size

2.5.1.1 Maximum volume

Height:	1520 mm
Width:	4210 mm
Length:	8250 mm

Table 67: Maximum volume for Concept-5

$$V = h * l * w$$

$$V = 1520 * 8250 * 4210 = 52.79 \text{ m}^3$$

The volume is quite large and this amount to a score of 2.

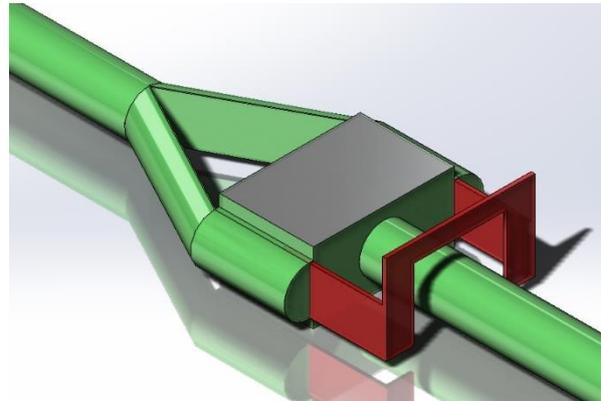


Figure 219: Energy dissipating box

2.5.1.2 Massiveness

The design contains no massive parts, and most of the design can be fulfilled by using sheet metal and welds. This amounts to a score of 6.

Criteria	Score
Maximum volume	2
Massiveness	6
Total score	4

Table 68: Weight & Size evaluation for Concept-5

2.5.2 Impact on surroundings

The control mechanism requires a lot of space to function, and the valve itself is large. It will be challenging to install this valve underground. Score: 2.

Criteria	Score
Impact on surroundings	2

Table 69: Impact on the surroundings evaluation for Concept-5

2.6 Concept-6 Plug

2.6.1 Weight & Size

2.6.1.1 Maximum volume

Height:	1000 mm
Width:	1000 mm
Length:	200 mm

Table 70: Maximum volume for Concept-6

$$V = h * l * w$$

$$V = 100 * 1000^2 = 0.1 \text{ m}^3$$

The valve is very small and will receive a score of 6.

2.6.1.2 Massiveness

The valve does not consist of any massive parts and it will receive a score of 6.

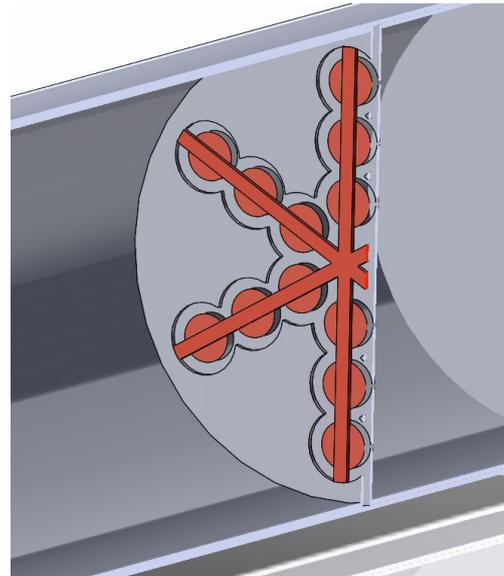


Figure 220: Mini pacifiers cross section

Criteria	Score
Maximum volume	6
Massiveness	6
Total score	6

Table 71: Weight & Size evaluation for Concept-6

2.6.2 Impact on surroundings

The valve does not use much space and will receive a score of 6.

Criteria	Score
Impact on surroundings	6

Table 72: Impact on the surroundings evaluation for Concept-6

2.7 Concept -7 Movable pipe 3

The sliding tube concept has a compact design where the energy dissipation is happening within the “pipe”.

2.7.1 Weight & Size

2.7.1.1 Maximum volume

Height:	1020 mm
Width:	1020 mm
Length:	1500 mm

Table 73: Maximum volume for Concept-7

$$V = h * l * w$$

$$V = 1500 * 1020^2 = 1.56 \text{ m}^3$$

This design is very compact and will thus receive a score of 5.

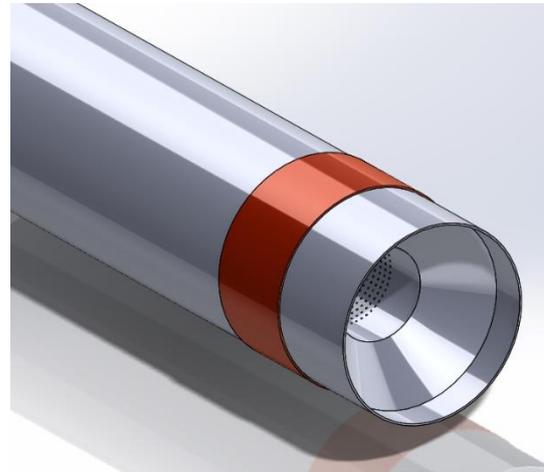


Figure 221: Sliding tube

2.7.1.2 Massiveness

There are no massive parts and will receive a score of 6.

Criteria	Score
Maximum volume	5
Massiveness	6
Total score	5.5

Table 74: Weight & Size evaluation for Concept-7

2.7.2 Impact on surroundings

The valve uses very little size and will thus receive a score of 6.

Criteria	Score
Impact on surroundings	6

Table 75: Impact on the surroundings evaluation for Concept-7

2.8 Concept-8 Rock block

2.8.1 Weight & Size

2.8.1.1 Maximum volume

Height:	- mm
Width:	- mm
Length:	- mm

Table 76: Maximum volume for Concept-8

The maximum volume of this concept is large so just by looking at the current design it will receive a score of 1.

2.8.1.2 Massiveness

The rock blocks are massive, but not expensive and it will thus receive a score of 5.

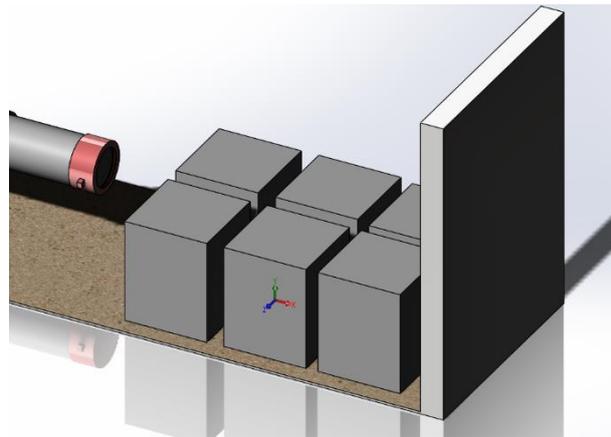


Figure 222: The Rock

Criteria	Score
Maximum volume	1
Massiveness	4
Total score	2,5

Table 77: Weight & Size evaluation for Concept-8

2.8.2 Impact on surroundings

The concept will use a lot of space and will most likely require an outside area. It will also require a significant geological intervention if it will be installed underground.

Criteria	Score
Impact on surroundings	1

Table 78: Impact on the surroundings evaluation for Concept-8

2.9 Concept-9 Rotary cylinder

The rotary cylinder is a valve that controls the flow with a rotating cylinder. This is a semi-compact design.

2.9.1 Weight & Size

2.9.1.1 Maximum volume

Height:	2600 mm
Width:	2600 mm
Length:	3700 mm

Table 79: Maximum volume for Concept-9

$$V = h * l * w$$

$$V = 3700 * 2600^2 = 25 \text{ m}^3$$

The size is quite large and it will receive a score of 3.

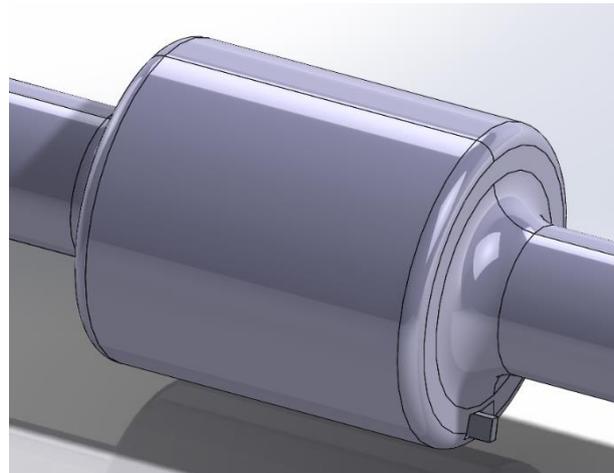


Figure 223: Rotary cylinder

2.9.1.2 Massiveness

There is no massive parts and it will receive a score of 6.

Criteria	Score
Maximum volume	3
Massiveness	6
Total score	4,5

Table 80: Weight & Size evaluation for Concept-9

2.9.2 Impact on surroundings

The valve does not use substantial more space than the pipe and the control mechanism is compact. The score is 4.

Criteria	Score
Impact on surroundings	4

Table 81: Impact on the surroundings evaluation for Concept-9

2.10 Concept-10 Maze

The flower petal design concept rotates to control the flow. It is compact but has some massive parts.

2.10.1 Weight & Size

2.10.1.1 Maximum volume

Height:	1000 mm
Width:	1000 mm
Length:	200 mm

Table 82: Maximum volume for Concept-10

$$V = h * l * w$$

$$V = 200 * 1000^2 = 0.2 \text{ m}^3$$

Very compact design and will receive a score of 6

2.10.1.2 Massiveness

The parts are milled out of massive plates and therefore it will receive a score of 3.

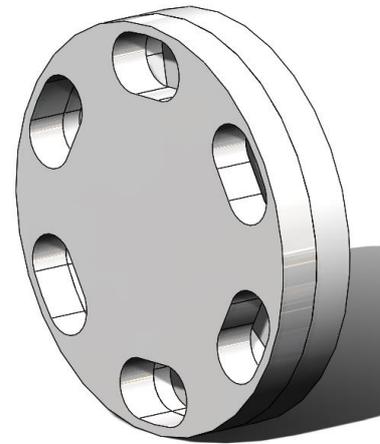


Figure 224: Maze design

Criteria	Score
Maximum volume	6
Massiveness	3
Total score	4,54

Table 83: Weight & Size evaluation for Concept-10

2.10.2 Impact on surroundings

The valve uses little space and will receive a score of 6.

Criteria	Score
Impact on surroundings	6

Table 84: Impact on the surroundings evaluation for Concept-10

3 Summary

Below, the final scores the concept received in these two criteria are summarized.

3.1 Weight & Size

Concept	Score
Concept-1 Bucket	1.5
Concept-2 Movable pipe 1	5.5
Concept-3 Jet Valve	4.5
Concept-4 Movable pipe 2	3.5
Concept-5 Energy dissipating box	4
Concept-6 Mini pacifiers	6
Concept-7 Movable pipe 3	5.5
Concept-8 Rock block	2.5
Concept-9 Rotary cylinder	4.5
Concept-10 Maze	4

Table 85: Results after the weight & size evaluation

3.2 Impact on surroundings

Concept	Score
Concept-1 Bucket	1
Concept-2 Movable pipe 1	6
Concept-3 Jet Valve	5
Concept-4 Movable pipe 2	4
Concept-5 Energy dissipating box	2
Concept-6 Mini pacifiers	6
Concept-7 Movable pipe 3	6
Concept-8 Rock block	1
Concept-9 Rotary cylinder	4
Concept-10 Maze	6

Table 86: Results after the impact on surroundings evaluation

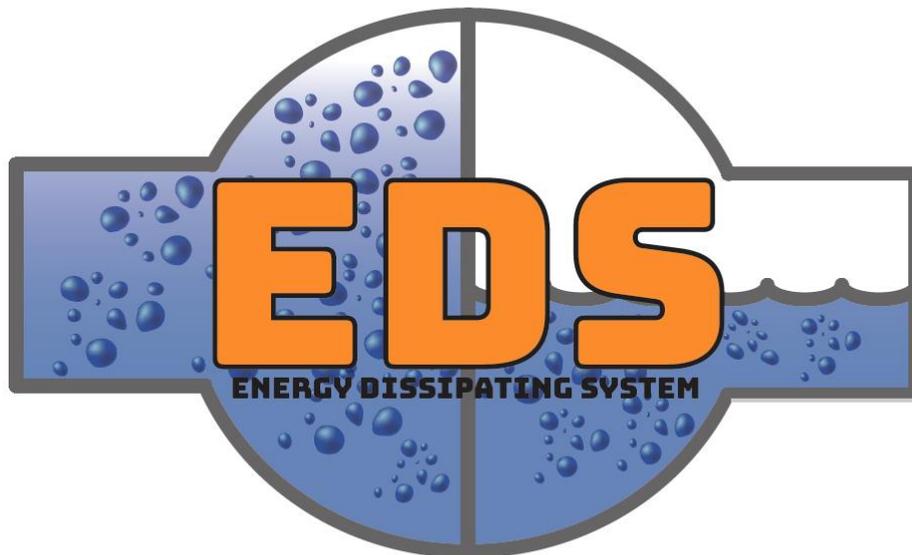


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Design of bypass valve

Appendix G: Criterion analysis –
Production method

22.05.2018



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Abstract

Background: Production Method is one criterion that will be compared in a Pugh-matrix to select the final concept.

Method: for the evaluation of the production methods of the different concepts the group has used their knowledge and external information. First, the influence factors of the cost and the main expected production methods are explained in relation with the actual task. Then, each concept has been evaluated in terms of the standardization of its components, the type and amount of joining required, and the manufacturing costs of the custom components.

Results: after the analysis, each component has been graded from 1 to 6 in the three aspect considered, and a final grade has been acquired by combining the three subcriteria. The best graded concepts are the Maze (6), sue to the small size and simplicity of its components, and the Rock Block (5.4) because of the minimum joining and the simplicity of its parts. In the other side, the Moveable Pipe 2 has been the worst (1) due to the high complexity of its parts, which requires a more expansive production method.

The resulting estimated cost of production is just an estimation for the comparison, it cannot be taken as a real cost estimation.

Document history

Version	Date	Author	Description
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0.02	20.03.18	MH	<ul style="list-style-type: none">• Started filling in description of evaluation
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1 Introduction

When it comes to the production of the system there are many factors that come into play.

The amount of parts will greatly affect the outcome in regards of cost. However, not all parts will affect the cost to the same degree. E.g. the main body of the valve will be much costlier than the bolts holding it together. And seeing as the concepts are still not fully developed, the amount of screws etc. needed has yet to be decided. Because of these reasons, only the major components of the system will be taken into consideration when evaluating the production costs.

2 Custom vs standardized parts

The biggest differentiator when it comes to the production of the system is if it's custom made parts or if the parts used are standard. This means that if the part must be made specifically for the system, it will be more expensive than a part that already has other uses.

Regarding this project, the main part will be the valve body. Seeing as the pipe diameter of the concepts has been made to fit in 1 m, the valve must be at least 1 m in diameter. As this is a huge part, the making of it will require a lot of time, effort and resources. Not only in the initial making of it, but also the processing that comes along. By using premanufactured parts, the making of the body itself will already be done. Of course, some alterations to the body might occur, but most likely nothing too extensive. This means that the only part left to do is the further processing of the body, which significantly reduces the cost.

For the project, this means that a system which consists of standardized parts is preferable compared to a system that has custom made parts. Naturally there can be a mix of the two, with some custom parts and some standardized parts.

3 Number of hours

The number of hours needed to produce a system will naturally play a part in how much the system will cost. There are multiple factors that come into play when calculating the number of hours that is needed to complete a system. The main factor is the amount of processing needed, and what type of processing. In a process, both the cost of the factory worker and the cost of the process itself must be taken into consideration.

4 Joining

Seeing as the system will consist of multiple parts, these parts will have to be joined. Depending on the system, the extent of this process will vary. If a system is made of few parts, it will most likely be a quicker and easier procedure than for a system consisting of many parts. That being said, there are several ways to join parts. Primarily for this system there are two primary ways of joining two parts: assembly and welding. Subject to the geometry and complexity of the system, permanent welding will be the overall cheaper choice. Keeping this in mind, sometimes temporary fastening is required.

4.1 Temporary

In this setting, the joining of two parts is meant as a reversible process. E.g. by using bolts, fittings, etc. This will be the preferable way of joining two parts if the parts must be taken apart at a later point in time. If the system has a part that must be changed on a regular basis, it would be unnatural to weld it in place. This process requires some preparatory work, e.g. drilling holes. Although this is a rather quick procedure, it is still something that must be done and something that will add to the overall cost and time consumption.

When fastening something using nuts and bolts, no matter how hard they are tightened, it will still be left a gap between the parts. As this is a system containing high pressure water, the water will get into all crooks and crevasses. This is problematic as it can cause leaks, and even destroy parts. To avoid this, seals must be put in place. This will naturally affect the price and the time it takes to assemble and disassemble the system.

4.2 Permanent

For this system, permanent joining is welding. It is a non-reversible process, meaning that when two parts are welded together they are permanently fixed. In this case, preparation of the surfaces is needed. Welding itself is a time-consuming process, which will greatly add to the overall production-time and cost of the system. However, the benefit of welding is that it won't leave any creases or crevasses for the water to get into, it will be completely tight.

5 Processing

The processing of the parts will be a factor that influences the outcome immensely, in regards of cost and time. Some of the processes are more time-consuming than others, while other might be more expensive.

Seeing as each concept will need different kinds of processing to be completed, the concepts can vary tremendously in price. It is therefore important that the group has a good understanding of how expensive and time-consuming each process is. That way the most fitting processes can be chosen for each concept. Some of the alterations that must be done to the concept might be done by several processes, the price of each process will then decide which will be chosen.

These processes are all processes done by a factory worker or with the supervision of a factory worker. That means that the salary of the worker must be taken into account. The avg. price of a factory worker is 750 NOK/hr. This is the price the group will base this evaluation on. Some of the processes are inexpensive in themselves but is costly since a factory worker must do them, while other processes are expensive to perform, but only last for a short period of time. E.g. welding is a cheap process in itself but is time-consuming, making the overall cost high.

5.1 Welding

As mentioned earlier, welding is one of the primary joining processes, regarding this system. The process requires some preparatory work. The surfaces must be ground and cleaned, so that no foreign materials like dirt, paint or other materials, get into the welding zone. The welding process is a process that in this case must be performed by a worker, not a machine.

This means that the cost of the worker must be considered. Naturally, the extent of welding will affect the price of the welding process. A welder will be able to weld 4 m/hr.

5.2 Casting

Casting is a process used for custom pieces, as it provides almost any shape. It needs a later machining to provide the required surface finish. As it is a custom design it has some fix costs apart from the material.

Here it is the relationship between the cost and the weight for casting from the company Dandong Foundry (Dandong Funding Engineering Machinery co., 2014):

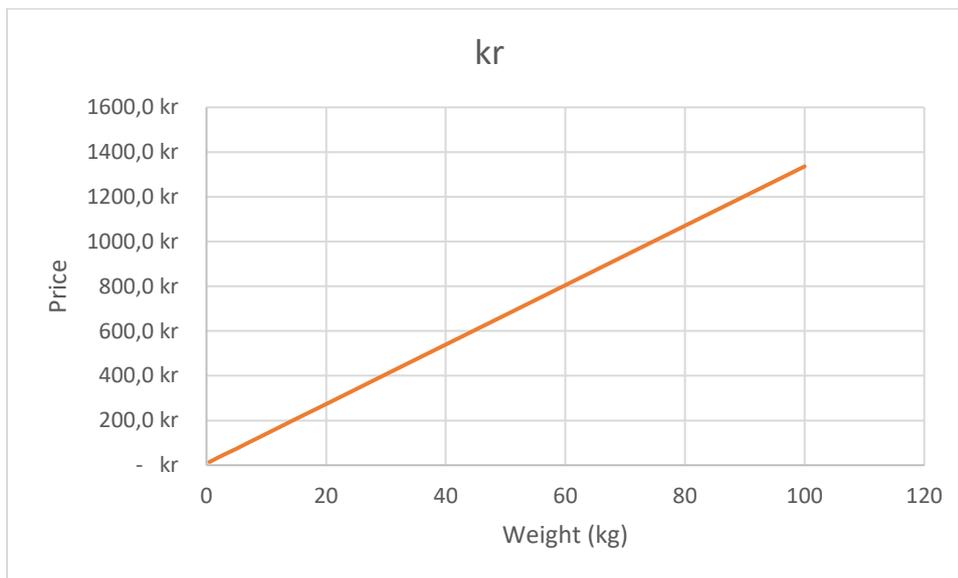


Figure 225: Price of casting depending on the weight of the piece (Dandong Funding Engineering Machinery co., 2014)

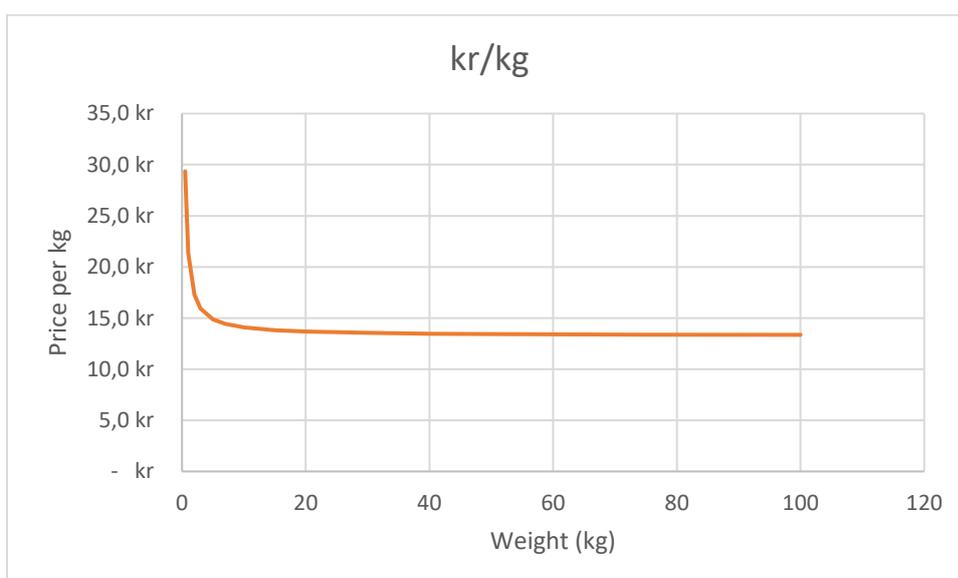


Figure 226: Price per kilogram of casting depending on the weight of the piece (Dandong Funding Engineering Machinery co., 2014)

5.3 Turning

The turning process is one of the main processes if the part is custom made by using casting. As casting isn't 100% accurate, some of the material will have to be taken off. This is where the turning comes in. The turning is mostly used on the contact-surfaces as it is important for the sealing of the system that these are completely straight. Depending on the size of the system, the turning can take anything from hours, to days. Seeing as the group is working primarily on smaller systems, it is assumed that the time spent turning will be 6 hours. An average price per hour for turning is 500 NOK/hr.

5.4 Surface treatment

To increase the durability of the system, the surfaces in contact with water are coated. The surfaces are coated with a type of painting that is resistant to wear, corrosion and other abrasions. This increases the lifetime of the system drastically. Standard price for this kind of paint is 700 NOK/m², cost of factory worker not taken into account.

5.5 Other

Other processes that must be done include cutting, drilling and grinding. These are all smaller processes that are done in-between the other processes. These smaller processes aren't related to any cost other than that of the factory worker. These processes are heavily linked to the complexity of the system.

6 Analysis Process

Due to the complexity of this criterion, the group has divided it into three different subcriteria: the number of custom vs standard parts, the amount of temporary vs permanent joining and the estimated manufacturing cost of the custom parts. For each criterion, a mark has been given. And then, they are combined to get the final mark for each concept.

The analysis of each subcriterion has been applied to each component of each of the concepts.

6.1.1 Number of custom vs standard parts

In this subcriterion, the group has analyzed how standard are the components of each concept. For this purpose, each component has been classified as custom or standard.

A component can be defined as custom if at least one of its parts cannot be acquired directly, or with minimal changes, from an industrial serial production. If a component is fully composed by standard parts but these parts must be joined, it will be still considered a standard component, but the cost of this joining will be added to the processing cost subcriterion.

The grading system consists in comparing the percentage of standard components each concept has. The more standard parts, the higher the grade is.

Concept number	Concept	Components	Number of Standard	% Standard	Standard vs custom grade
Concept-1	Bucket	1	0	0%	1.0
Concept-2	Moveable pipe 1	2	1	50%	4.1
Concept-3	Jet Valve	5	1	20%	2.3
Concept-4	Moveable pipe 2	2	0	0%	1.0
Concept-5	Energy dissipation box	5	4	80%	6.0
Concept-6	Plug	2	1	50%	4.1
Concept-7	Moveable pipe 3	2	0	0%	1.0
Concept-8	Rock block	3	1	33%	3.1
Concept-9	Rotatory cylinder	2	0	0%	1.0
Concept-10	Maze	3	2	67%	5.2

Table 87: Standard vs Custom Subcriterion results

6.2 Amount of temporary vs permanent joining

For the analysis of the joining between components, the group has separated the connections into two different types: temporary and permanent. Temporary is referred to connections that can be separated and joined again after the installation. The permanent parts are those which will stay connected from the installation, this connection is basically welding.

In this subcriterion, only fixed connections between components or inside components, have been considered. The connecting components with differential movement are not the objective of this document.

The characteristic of temporary can be applied to a component when, at least, one connection between its parts or to other component cannot be permanent for the installation or the maintenance requirements.

The final grade of this subcriterion has been obtained directly from the percentage of permanent components joined. The more permanent components, the higher the mark is.

Concept number	Concept	Components	Number of Permanent	% Permanent	Temporary vs permanent grade
Concept-1	Bucket	1	1	100%	6.0
Concept-2	Moveable pipe 1	2	1	50%	3.5
Concept-3	Jet Valve	5	3	60%	4.0
Concept-4	Moveable pipe 2	2	0	0%	1.0
Concept-5	Energy dissipation box	5	4	80%	5.0
Concept-6	Plug	2	1	50%	3.5
Concept-7	Moveable pipe 3	2	1	50%	3.5
Concept-8	Rock block	3	3	100%	6.0
Concept-9	Rotatory cylinder	2	1	50%	3.5
Concept-10	Maze	3	2	67%	4.3

Table 88: Temporary vs Permanent Subcriterion results

6.3 Estimated processing cost of the custom parts

For this estimation, the group has gone through every component defining a production method. This estimation has only been applied to the custom parts and the joining of this parts. This is because the standard parts have been already considered in the first subcriterion.

After this, the manufacturing costs explained in previous sections have been used to calculate the final processing cost of each concept. The resulting cost only takes in account the manufacturing process, the material cost is not the objective of this document.

Concept number	Concept	Processing Cost	Processing Cost Grade
Concept-1	Bucket	39,325 kr	3.2
Concept-2	Moveable pipe 1	14,351 kr	5.8
Concept-3	Jet Valve	47,577 kr	2.3
Concept-4	Moveable pipe 2	60,036 kr	1.0
Concept-5	Energy dissipation box	57,451 kr	1.3
Concept-6	Plug	23,291 kr	4.8
Concept-7	Moveable pipe 3	19,533 kr	5.2
Concept-8	Rock block	13,249 kr	5.9
Concept-9	Rotatory cylinder	60,166 kr	1.0
Concept-10	Maze	12,029 kr	6.0

Table 89: Processing Cost Subcriterion results

7 Results

To combine the previous results of each subcriterion in a final grade for the Pugh-matrix the group has set a weight to each of them to acquire a final grade. The weights decided are based on the knowledge and the information the group has about production methods. The weights have been set depending on the strength of the relationship of each subcriterion with the final production cost.

Grading weights	
Subcriterion	Weight
Number of Standard parts	40%
Number of Permanent parts	20%
Cost	40%

Table 90: Weights applied to each subcriterion to acquire a final grade for the whole criterion

By multiplying each grade by its corresponding weight and adding the grades from all the criteria, results the final grade.

Concept		Standard vs Custom	Temporary vs Permanent	Processing Cost	Final Grade
Weight		40%	20%	40%	
Concept-1	Bucket	1.0	6.0	3.2	3.1
Concept-2	Moveable pipe 1	4.1	3.5	5.8	5.2
Concept-3	Jet Valve	2.3	4.0	2.3	2.9
Concept-4	Moveable pipe 2	1.0	1.0	1.0	1.0
Concept-5	Energy dissipation box	6.0	5.0	1.3	4.4
Concept-6	Plug	4.1	3.5	4.8	4.8
Concept-7	Moveable pipe 3	1.0	3.5	5.2	3.5
Concept-8	Rock block	3.1	6.0	5.9	5.4
Concept-9	Rotatory cylinder	1.0	3.5	1.0	1.6
Concept-10	Maze	5.2	4.3	6.0	6.0

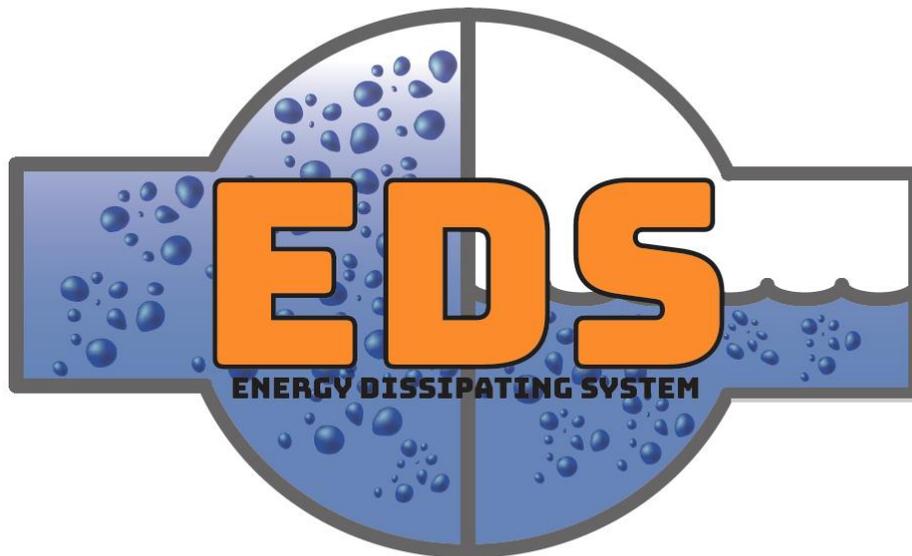
Table 91: Resulting grades of the Production Method Criterion



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Design of bypass valve Appendix H: Criterion analysis – Complexity

22.05.2018



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Abstract

Background: Complexity is one of the criteria that will be compared in a Pugh-matrix to select the final concept.

Method: As an evaluation of the complexity of each concept, the group has divided this criterion into five sub-criteria. The sub-criteria are: number of parts, number of moving parts, difficulty of assemble, ease of access and ease of service. All these sub-criteria are combined to acquire a final grade of Complexity for each concept.

Results: All the concepts received a score from 1 to 6. The best concept is the Maze, with a grade of 4.4, because it only has two parts and they are very simple. In the other side, the concept Plug has the lowest mark, 2, due to the great number of parts and its difficulty on assembly and access.

Document history

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0.02	08.03.18	MH	<ul style="list-style-type: none">• Removed degree of movement• Removed service/ease of access
1.0	09.03.18	OO	<ul style="list-style-type: none">• Proofread document• Edited document structure
1.01	15.05.18	JS	<ul style="list-style-type: none">• Proofread document

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1 Introduction

In this document the parameter “complexity” will be described, evaluated and used. The output of this parameter will be a central part in the selection process of the concepts. It’s therefore important that this parameter, along with the others, are made properly. This will ensure that the best concept will be chosen.

2 Complexity

Complexity can be defined in many ways. The common nominator is that they all include amount of parts in a system, and how hard it is to understand or complete. All of these are factors that come into play in throughout this project. Complexity therefore, plays a huge part in this project and must be handled carefully and taken seriously. Underneath is the factors taken into consideration for the complexity parameter.

2.1 Parts

Although there are many factors that define complexity for this project, it will be first and foremost the parts that define the complexity of a concept. If a concept has many parts, it is more likely to fail than a concept that has fewer parts. This is something that can be mitigated through good engineering but is still something to keep in mind. It is therefore a goal to have as few parts as possible. This will normally also affect the total cost of the concept as well.

2.2 Moving parts

The amount of moving parts is also something that defines the complexity of the concept heavily. Moving parts are also exposed to wear and tear in a different way than static parts. Not only are they in contact with the elements, but also with other parts. This means that moving parts often have to be replaced sooner than stationary parts, if not accounted for during the design-process. Moving parts also increase the chance of failure drastically, simply because there are more things that can go wrong. Of course, the degree of movement also matters. A part that moves a lot will be more exposed than a part that only moves a bit.

2.3 Assembly

As mentioned earlier, the amount of parts plays a huge role in the complexity of the concept. Not only because there are more things that can go wrong, but also because the parts have to be connected to assemble the concept. Moving parts naturally make this process even more challenging.

2.4 Ease of access

The ease of access to a system is something that is important to think about, but often overlooked. If a system is buried underground, it would have to be dug up for every service of it. If it is inside a room, the cost of the room will have to be calculated into the overall cost of the system. If it’s outside, it is easy to access but is exposed to the weather. Even the most solid valves must be inspected and checked on a regular basis. This factor is therefore important.



2.5 Service

The service of a system is something that varies a lot from system to system. If a system is complex, hard and tedious to service, the costs will naturally be high. The service of the system is therefore something that should be thought of during the design process. A simple service normally equals a cheap service.

3 Complexity matrix

Taking these factors into consideration will form the final complexity value for each concept. To combine these factors, a complexity-matrix is used. The complexity matrix is simply a Pugh-matrix with the complexity factors operating as the parameters.

The way this matrix works is by rating each concept on a scale of 1 to 6 (6 is good, 1 is bad) in each factor. Then taking the average of all the scores for each concept.

Concept	Bucket	Movable pipe 1	Jet valve	Movable pipe 2	Energy dissipating box	Plug	Movable pipe 3	Rock Block	Rotary Cylinder	Maze
Parts	2	4	3	2	5	1	3	3	3	4
Move	3	3	5	3	5	4	3	3	4	5
Assem	2	3	3	3	3	1	3	3	4	5
Access	3	3	3	2	5	3	3	6	4	3
Service	2	2	1	1	3	1	2	5	2	5
Total	2.4	3.0	3.0	2.2	4.2	2.0	2.8	4.0	4.2	4.4

Table 92: Complexity matrix

4 Final scores

As the concepts are yet subjected to change, it will be hard to estimate the amount of parts etc. These scores are therefore a rough estimation.

4.1 bucket

As this concept only is one big block, it has no moving parts. The thing that has the moving parts is the valve, which is the “movable pipe 3” concept. The hardest part to assemble here is the valve. Seeing as the bucket is one huge block, it would have to be made on the spot. Or in best case made in sub-parts and then transported to the facility. Both which would require a vast amount of resources.

The maintenance of the Bucket concept is split into two parts; the valve and the bucket. The bucket itself is easy to get to and simple to clean and maintain. Even though it is massive, it should be an easy task to clean seeing primarily consists of larger surfaces. The valve on the other hand will be a bit harder. Although it is a pretty simple valve, the maintenance will be harder as you have to open the main pipe in some way.

4.2 Movable pipe 1

It consists of multiple moving parts, but nothing too complicated. The degree of movement is limited and doesn't add much to the overall size or complexity of the concept. The assembly might cause issues as it has to be worked into the pipe. The pipe itself must also be altered in order to get a good seal.

Once you get access to the system, it is easy to service. The problem is getting access to it. Seeing as it is inside the main pipe, the main pipe would have to be altered to get easy access to the system. If not, the main pipe would have to be disassembled to get access to the system. The service of the system will be simple as it consists of few parts.

4.3 Jet valve

Although the jet valve only has one moving part, it has a lot of stationary parts. The moving part only rotates which is a big bonus. The assembly will require quite a lot as the parts are big and heavy. On the positive side the valve can be assembled in its entirety at a remote location. The service of this concept will be horrible as it consists of multiple grids and will have to be completely disassembled to be serviced.

Seeing as the body of the Jet valve is custom, it would be simple to put in a service-hatch. The accessibility is therefore not the biggest problem. The hard part is the actual service. To do this the valve will have to be disassembled. This must be done in order to get access to the rotating plate, which is one of the main parts of this concept.

4.4 Movable pipe 2

As this is a slightly larger and more complex concept, it consists of more parts as well as more moving parts than the two other movable pipe concepts. The amount of parts and the structure of the concept causes it to require a lot of assembly. Although there is a lot of movement, this happens on the inside of the casing.

The construction of this system makes it hard to access. It is based on multiple layers, meaning you must go through several layers to get access to the whole system. For the same reason it will be hard to service.

4.5 Energy dissipating box

Although it consists of a lot of parts, many of these are standardized, making them cheap. There is only one moving part, but it moves a lot and is in contact with a lot of surfaces. The assembly of this concept will not be too hard as the standardized parts usually are easy to mount. The parts that are not standardized are small enough so that they can be assembled at a remote location if necessary.

As the pipes used in this system is standardized, there already exists procedures for servicing and maintaining these. The complicated part is the box. The shape of it makes it easy to access, but that doesn't mean that it will be easy to service. The system is based on multiple grids, which makes the servicing process harder. The moving mechanism also complicates the service.

4.6 Plug

The amount of parts in this concept is outstanding, in a bad way. Just counting the plugs alone is 50 parts. Even though all of them move, it is the outer pipe that is the real moving part, as all the plugs are connected to this. The assembly of this concept will be easy but very time consuming. As with the moving pipe concepts, this concept slides on the outside of the main pipe. This means that the main pipe has to be altered to a certain degree.

The accessibility to this system is the same as the Movable pipe 1 concept, as the moving mechanism is based on the same principle. This means a hatch of sorts would have to be installed in order to make it more accessible. The service will be horrible as it has many parts and holes, and a large surface which is exposed to friction.

4.7 Movable pipe 3

Same as “movable pipe 1”, multiple parts but nothing too complicated. Slightly bigger movement-pattern due to the fact that it must cover all the holes on the perforated tube. The assembly is the same as with “movable pipe 1”. The pipe must be altered a bit to accept the new concept and to prevent leakage.

This concept has the same problem with accessibility as the Movable pipe 1 concept. when it comes to the service of the system, the main problem will be the moving part. This part has two large friction surfaces; the surface in touch with the main pipe and the surface covering the perforated pipe. This friction means that the system has to be serviced more regularly.

4.8 Rock block

As the valve in this concept is based on the valve in “movable pipe 1”, these share the same features. Few parts, and not moving very much. The difference is that this will be installed at the end of the pipe, making the installation much easier. The rock blocks in this concept are really basic. Just nets formed into boxes and filled with rocks. The assembly of this concept will be one of the easier ones. The downside to these blocks is that they have to be placed there, and they are big and heavy.

This concept consists of two parts; the valve and the blocks. Both parts are outside, meaning they are easily accessible. The service of both parts are simple. The service on the blocks is pretty much neglectable. While the service on the valve is the same as in the Movable pipe 1 concept.

4.9 Rotatory cylinder

The rotatory cylinder shares the shape of “movable pipe 2” to a large extent. The difference being that the movable pipe is inside the main pipe, while this concept has its own chamber to operate in. The movement is very limited, rotary and on the inside of the assembly. The assembly shouldn't be too difficult other than the parts being big and heavy.

As this concept has a custom-made casing, it would be easy to add a service-hatch to the design. This means that the system is easily accessible. The service of the system will be a bit harder as there are large surfaces of friction, some over a perforated tube.

4.10 Maze

This concept is very basic and only consists of two parts, one being a moving part. The assembly is therefore very easy. As the movement in the concept only is rotary, it scores high also in this factor.

The access to this system is depending on the pipe around it. Most likely a service-hatch will have to be installed. Seeing as this concept is as simple as it is, there aren't many parts to think of. The few parts in the system all have basic geometry and large surfaces. Although there are some surfaces exposed to friction, these are not enough to complicate the servicing.



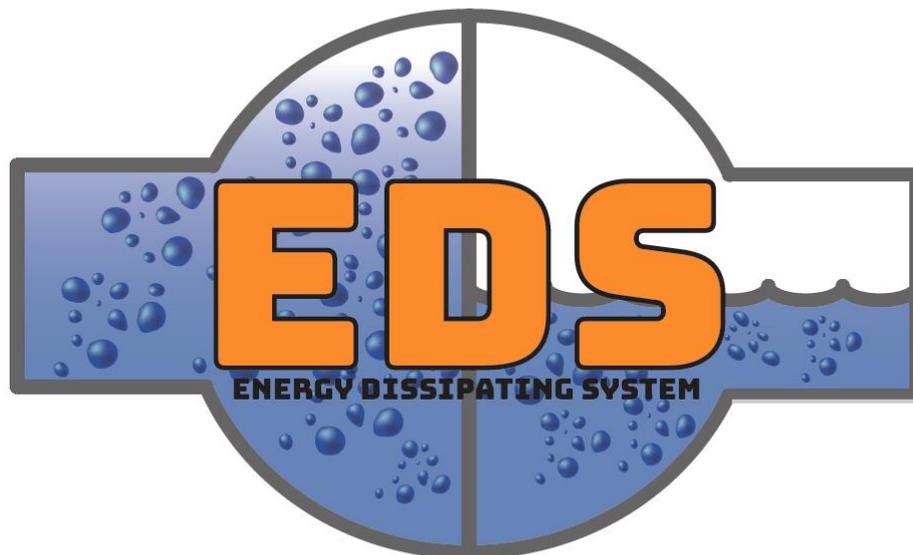
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Design of bypass valve

Appendix I: Criterion analysis –

Control mechanism

22.05.2018



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Abstract

Background: Control Mechanism is one of the criteria that will be compared in a Pugh-matrix to select the final concept.

Method: For evaluating the possible further cost of the control mechanism, three subcriteria has been set. These criteria are defined by geometrical dimensions of the concepts. The criteria are: potential opening/closing force, the length of the opening/closing movement and the length of the sealing. Each subcriterion is evaluated separately for acquiring a grade, and then, these grades are combined to give them a final grade.

Results: The grades variate a lot from some concepts to others. The concept Rotatory Cylinder has the highest grade (5.8) due to the direction of the force, which is perpendicular to the pressure force, and the short length of the movement. On the other side, the concept Moveable Pipe 2 acquired the lowest grade (2.3) due to its long opening/closing movement, and the direction of the movement is against the pressure force with a great area of actuation.

Document history

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0.01	02.03.18	JS	<ul style="list-style-type: none">• Created the document
0.02	06.03.18	JS	<ul style="list-style-type: none">• Proofreading and improving
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1.00	09.03.18	MH	<ul style="list-style-type: none">• Proofreading
2.00	17.05.2018	LH	<ul style="list-style-type: none">• Proofreading and rewriting to better convey the message

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1 Introduction

The control mechanism involves several parts. Most important is the actuator that will deliver force to change the flow rate.

The main goal of this document is explaining the considerations the group have over the control mechanism cost. Through these considerations, the different concepts are evaluated. The criteria considered are an estimation of a possible cost of the control mechanism. The ease of implementation is another goal of this document.

It should be noted that the criteria that the concepts are rated in are simple calculation based on geometrical analysis of the concept. These calculations provide a comparable idea of possible costs of the control mechanism. No strength or flow analysis has been run in this criterion.

The requirements linked:

1.1 RQ-8

“The system MUST be controlled autonomously in compliance with guidelines from NVE”

1.2 RQ-9

“The System MUST be regulated in compliance with “maskinforakriften””

2 Criteria definition and application

For a faster comparison of the concepts the group have created parameters which relate the geometry of each concept with the cost of the control mechanism. These parameters are the surfaces, lengths and angles; and they have been combined to express the relation they have with the force. These parameters are a combination of geometrical dimensions from each CAD model.

Every parameter is graded from 1, the worst mark, to 6, the best mark. To conserve the relationship between the force and the parameters, the variation of the scale used to translate the obtained values into grades is the same these parameters has with the force. For example, one parameter used to consider the necessary force of the actuator is the surface under pressure. The variation the force has with this surface is linear, so the variation of this parameter with the grading scale is also linear. However, the angle this surface has with the movement of the mechanism has a sinusoidal dependency with the force, so the variation of the grading scale has a sinusoidal relationship with this parameter.

2.1 Necessary opening/closing force

This is the most important criterion, as it defines the size and the power needed for the control mechanism. The main source of force is the pressure difference between the inlet and the outlet, and how it is related with the opening/closing movement. Another force to be considered is the friction force during the opening/closing movement. The final score in “Necessary opening/closing force” will be determined by prioritizing the pressure force by 80% of the final score and the friction force by 20%. These priorities are a result of discussions in the group based on our knowledge.

The next sections explain the parameters used and its relationship with the grading scale

2.1.1 Pressure force

This force come from the difference of pressure between the inlet and the outlet of the valve. A pressure value will not be used as it is the same in every concept. To create a grading system, the parameter selected is a combination between the surface under this pressure and the angle this surface has with the opening/closing movement.

$$F \propto Surface * \sin(angle) \quad (1)$$

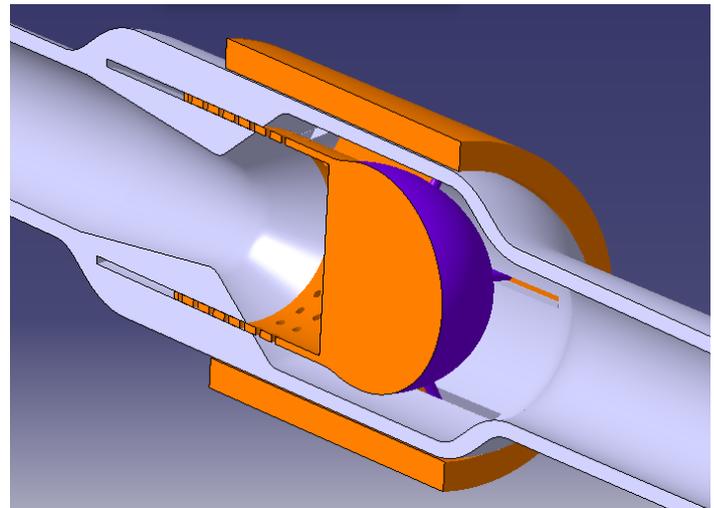


Figure 227: The concept Moveable Pipe 2 with the surface of the pressure force in purple

As we can see in the Figure 227, the surface has a linear relationship with the force and the angle has a sinusoidal variation.

Magnitude - parameter	Relationship with the grading scale
Surface for the pressure force	Linear
Angle of the pressure force	Sinusoidal

Table 93: Relation of the pressure force with the parameters

Reference	Surface (m ²)	Angle (°)
Maximum	1.56	90
Minimum	0.09	0

Table 94: Reference values for the grading scale

We have represented the relation of the scale of the parameters in a table and a graph to illustrate better this relation.

Grade	Angle (°)	Surface (m ²)	sin(Angle)*Surf (m ²)
1	90.00	1.56	1.56
2	53.13	1.26	1.01
3	36.87	0.97	0.58
4	23.58	0.68	0.27
5	11.54	0.38	0.08
6	0.00	0.09	0.00

Table 95: Relation of the grading scale with the parameters of the pressure force

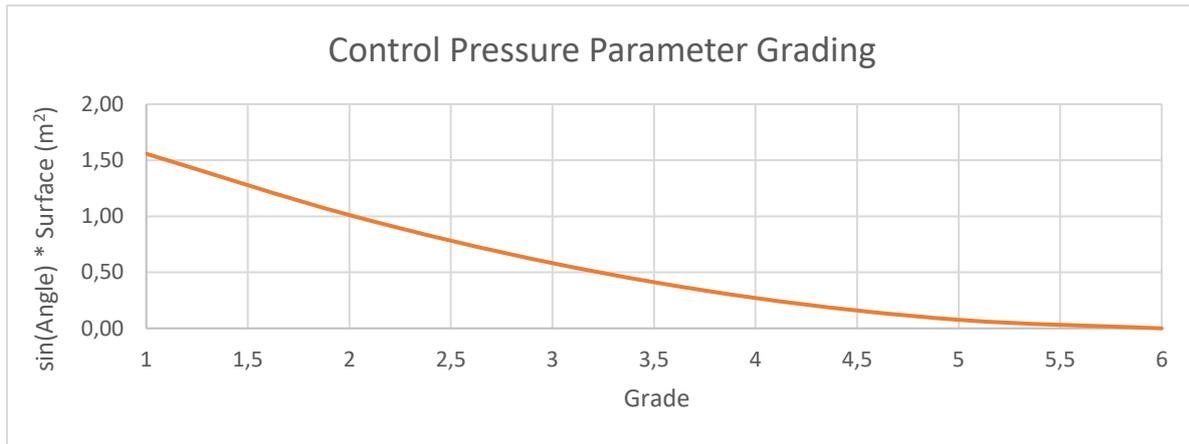


Figure 228: Relation of the grading scale with the parameters of the pressure force

2.1.2 Friction force

The source of this force is the friction between the elements of the opening/closing system. The dimensions considered to make the scale are the surface which will have friction during the opening/closing movement, and the minimum length of sealing needed. This length has been considered because it means a great source of friction.

$$F \propto Surface; F \propto length \tag{2}$$

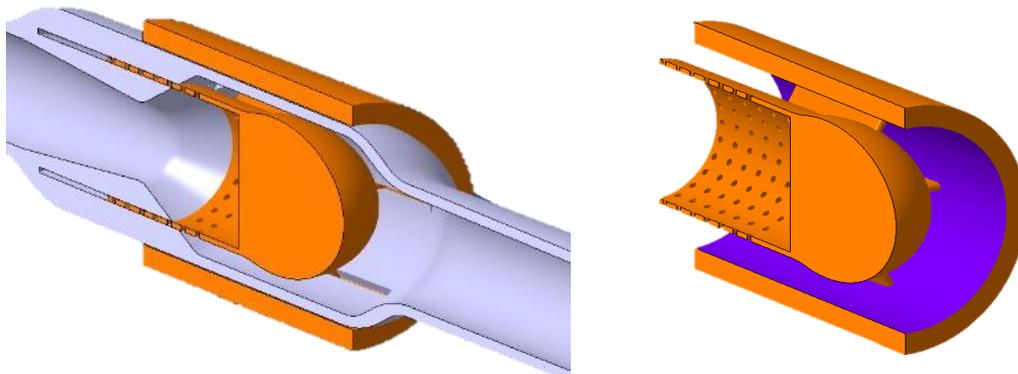


Figure 229: In purple, contact surface used to calculate the friction force parameter in the concept Moveable Pipe 2

The parameter decided to scale the concepts is the product of multiplying this surface with this length. These are the references and the relationships:

Magnitude - parameter	Relationship with the grading scale
Surface of the friction force	Linear
Length of the sealing	Linear

References	Surface (m²)	Length (m)
Maximum	8.58	16.00
Minimum	1.51	1.30

Table 96: Reference values for the grading scale

Table 97: Relation of the friction force with the parameters

The resulting scale:

Grade	Surface (m ²)	Length (m)
1	8.58	16.00
2	7.16	13.06
3	5.75	10.12
4	4.34	7.18
5	2.92	4.24
6	1.51	1.30

Table 98: Grading scale of the pressure force parameters

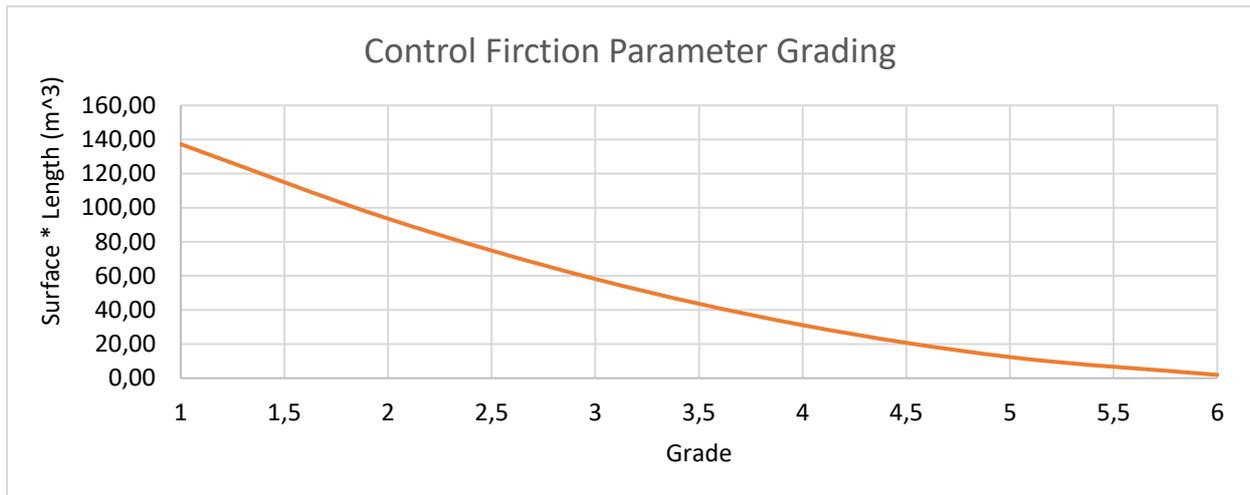


Figure 230: Relation of the grading scale with the parameters of the pressure force

2.1.3 Global comparison

As we said in the introduction of this section, the weights for the two forces are 80% for the pressure force and 20% for the friction force.

Concept		Pressure grade	Friction grade	Global grade
Weight		80%	20%	100%
Concept-1	Bucket	6	4	5.6
Concept-2	Moveable pipe 1	4	4	4.0
Concept-3	Jet Valve	6	4	5.6
Concept-4	Moveable pipe 2	1	3	1.4
Concept-5	Energy dissipation box	6	1	5.0
Concept-6	Plug	4	4	4.0
Concept-7	Moveable pipe 3	6	4	5.6
Concept-8	Rock block	4	5	4.2
Concept-9	Rotatory cylinder	6	5	5.8
Concept-10	Maze	6	4	5.6

Table 99: Global grade in the necessary force sub-criterion

2.2 Length of the opening/closing movement

In this section, we will consider the length the mechanism has to follow to change the status from fully open to fully close, or vice versa. The influence of this length is not as important as the force. However, it can increase the torque on some elements increasing some costs.

The grading scale is just based on this length, giving the maximum grade to the minimum length and vice versa.

References	Length
Maximum	3.00
Minimum	0.20

Table 100: Reference values for the length subcriterion

	Concept	Length (m)	Length Grade
Concept-1	Bucket	0.60	5.3
Concept-2	Moveable pipe 1	0.40	5.6
Concept-3	Jet Valve	0.20	6.0
Concept-4	Moveable pipe 2	2.00	2.8
Concept-5	Energy dissipation box	3.00	1.0
Concept-6	Plug	0.40	5.6
Concept-7	Moveable pipe 3	0.60	5.3
Concept-8	Rock block	0.40	5.6
Concept-9	Rotatory cylinder	0.40	5.6
Concept-10	Maze	0.86	4.8

Table 101: Grades of the concepts in the length sub criterion

2.3 Sealing

The sealing has been included in the control mechanism criterion because it is related with the moveable parts, and these parts are which compose the control mechanism. The two dimensions that is used to grade the sealing is the minimum total sealing length, and the length of the movement from closed to open of the sealed parts. The parameter obtained to translate into grades is the multiplication of these two measurements.

References	Length of sealing	Movement length
Maximum	16.00	3.00
Minimum	1.30	0.20

Table 102: References of the parameters of the sealing grading

	Concept	Length of sealing	Movement length	Scale	Sealing Grade
Concept-1	Bucket	7.85	0.60	4.71	5.6
Concept-2	Moveable pipe 1	6.28	0.40	2.51	5.8
Concept-3	Jet Valve	5.65	0.20	1.13	5.9
Concept-4	Moveable pipe 2	3.64	2.00	7.28	5.3
Concept-5	Energy dissipation box	16.00	3.00	48.00	1.0
Concept-6	Plug	6.28	0.40	2.51	5.8
Concept-7	Moveable pipe 3	7.85	0.60	4.71	5.6
Concept-8	Rock block	3.14	0.40	1.26	5.9
Concept-9	Rotatory cylinder	1.30	0.40	0.52	6.0
Concept-10	Maze	6.28	0.86	5.43	5.5

Table 103: Grades of the sealing subcriterion for each concept

3 Results

The sub-criteria have been combined assigning them a weight considering the influence each has on the final cost of a control mechanism.

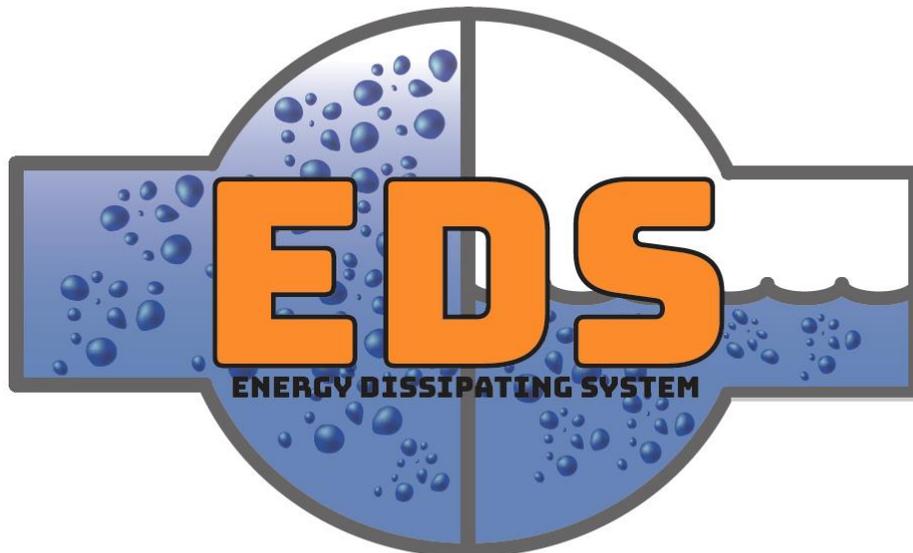
Concept		Force Grade	Length Grade	Sealing Grade	Final Grade
Weight		70%	10%	20%	100%
Concept-1	Bucket	5.6	5.3	5.6	5.6
Concept-2	Moveable pipe 1	4.0	5.6	5.8	4.5
Concept-3	Jet Valve	5.6	6.0	5.9	5.7
Concept-4	Moveable pipe 2	1.4	2.8	5.3	2.3
Concept-5	Energy dissipation box	5.0	1.0	1.0	3.8
Concept-6	Plug	4.0	5.6	5.8	4.5
Concept-7	Moveable pipe 3	5.6	5.3	5.6	5.6
Concept-8	Rock block	4.2	5.6	5.9	4.7
Concept-9	Rotatory cylinder	5.8	5.6	6.0	5.8
Concept-10	Maze	5.6	4.8	5.5	5.5

Table 104: Final grades in the control mechanism criterion

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Design of bypass valve Appendix J: Criterion analysis: Flow characteristic

22.05.2018



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Abstract

Background: Flow characteristics is one of the criteria that will be compared in a Pugh-matrix to select the final concept.

Method: To evaluate the flow characteristics SolidWorks flow simulation module was used. 11 planes was created at a 10% increment from fully closed to fully open. Flow simulation was done 11 times per valve to get the flow rate at each increment. The resulting flow rate was plotted in a graph to look at the flow characteristics.

Results: None of the concept had the “equal percentage” flow characteristic, but some had a characteristic approximately equal to the “linear opening”. The best concept was concept-1 with a linear opening. Concept 3 and Concept 7 had some slight deviations from linear opening, but still close. The worst concept was concept 6 with no clear characteristic.

Document history

Version	Date	Author	Description
0.00	20.03.18	JS	<ul style="list-style-type: none"> Created the document
0.01	20.03.18	OO	<ul style="list-style-type: none"> Added all simulation results except concept 9.
0.02	21.03.18	OO	<ul style="list-style-type: none"> Added "Flow characteristic" and "How evaluate the flow characteristic" Evaluated the concepts
0.03	22.03.18	LH	<ul style="list-style-type: none"> Described the test platform Description Added more pictures Proofread evaluations
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1.01	16.05.18	JS	<ul style="list-style-type: none"> Proofread
2.00	19.05.18	LH	<ul style="list-style-type: none"> Added abstract and finalizing

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1 Introduction

The valve that the group is designing must be able to control the flow rate of the water going through it. An unpredictable flow characteristic can lead to the reservoirs being emptied, or that too little water is being fed downstream. The flow characteristic criterion focusses on the relationship between the opening grade of the valve and the flow rate through it. The criterion will be measured by analyzing this relationship in SolidWorks Flow simulation. The method for doing so will be explained more thoroughly in *Chapter 0*.

1.1 System Requirements

This criterion aims to verify RQ-3¹. The system must have a predictable flow characteristic to be controllable in a real-life scenario. The valve opening stages must correlate to the same flow rate every time it is opened. For example, if a concept has a flow rate of $2 \text{ m}^3/\text{s}$ at 40% open, it must have this flow rate every time it is at 40%. It is too expensive to measure the flow rate and then adjust the valve opening accordingly, therefore the flow is controlled by knowing the flow rate at the opening percentages and then adjusting the valve. The simulations will be done with the parameters stated in RQ-1².

¹ The system MUST have a predictable flow characteristic

² The system MUST operate under the pressure of 100- to 300-meter water column.

2 Flow characteristic

When designing a control valve for an application, the flow characteristic can be as important as the selection of the valve size (Monsen, 2015). How the flow behaves through the system can have critical impact on the outcome of the system. The flow characteristic of a control valve can be defined as being the relationship between the flow rate and the valves positioning. By looking at the valves opening from 0 to 100% and the current flow rate presented in a graph, it is possible to get an understanding, and, an evaluation of how the valve is operating. There are two types of flow characteristics, inherent characteristic and installed characteristic. The inherent characteristic is based on tests where there is a constant pressure drop across the system, or valve in this case. The installed characteristic on the other hand will also take the pressure differential into account. A hydropower plant will in addition to the valve contain a large amount of piping, these will affect the volume flow rate and the pressure (Fisher controls international, 2001, p. 107)

The group has decided to look at the inherent characteristic for a few reasons. The first is that it gives us a simpler analysis than to include relative pressure. By defining the inlet and outlet pressure, SolidWorks will simulate a constant pressure drop. Evaluating the flow characteristic will also require a great amount of simulations because of the different regulation steps. If the group were to analyze different pressures for each regulation step as well, it would simply take too long time. At this point the concepts are rough designs and small changes might correct some errors. The main objective for the simulation of flow characteristic is to separate the concepts that clearly show a lack of potential.

2.1 Typical flow characteristic curves

There are three main inherent flow characteristics illustrated in *Figure 1*. The quick opening characteristics provides a large increase in flow rate at the start and reduces sharply in flow rate at the end stages. Valves with a quick opening characteristic is primarily used for on-off operation. The linear flow characteristic illustrates a proportional relationship between the flow rate and percentage of the opening. With a constant pressure drop the valve gain will be the same, thus a linear graph. The last curve is called an equal percentage characteristic. As seen from the graph the flow has a small increase in flow rate at the start and increase at the end stage. Valves with this characteristic is often used on applications where a large pressure drop occurs in the system itself (Fisher controls international, 2001, p. 108).

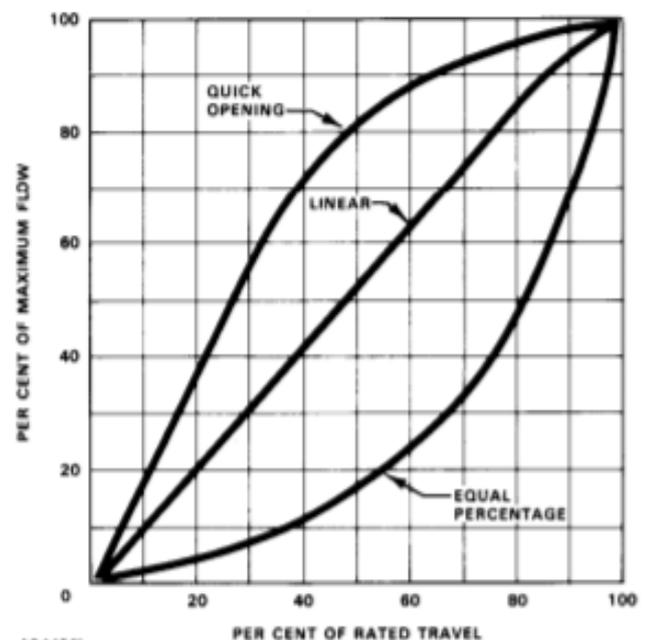


Figure 231: Inherent flow characteristic (Fisher controls international, 2001)

3 How to evaluate the flow characteristic

The ten concepts will be rated on a scale from 1 to 6 based on how well they perform in the flow simulations. Thus, it is imperative that the group has a good understanding of what is the desired flow. As explained in *Chapter 2.1* the “Equal percentage” is the desired characteristic. In the evaluation the group will consider if the valve has potential, as in if the flow is predictable. If the flow is predictable, either “Quick opening”, “Linear” or somewhere in between the graphs (Figure 231) it may require minor changes to the design to make the characteristic closer to “Equal percentage”. The rating will be lower if the characteristics are unpredictable. Irregularities, or results from the simulations that just don’t make sense will also be considered when rating the concepts.

4 Simulation Setup

The flow characteristics were measured using Flow simulation in SolidWorks. This criterion only focuses in how the flow rate through the valve changes when the valve is going from 100% open to 0% open. Therefore, the maximum flow rate may vary in each concept. The only way to simulate the valve closing in SolidWorks is manually. This involves adjusting the valve opening to the correct amount and then running a simulation for that specific opening percentage. More simulations from 100% opening to 0% will give more accurate results, but also take much more time. We decided to use 11 simulations, from 0% to 100% opening and with an increment of 10% between the simulations. This gives a good balance between accurate results and time usage.

To do the analysis the closed and 100% open positions of the valve where defined, and two planes in SolidWorks where created. Then 9 more planes where created with an equal distance between them, so we are left with 11 planes with a 10% increment between them as shown in *Figure 232: Planes in SolidWorks*.

The simulations where set up in the same manner as in the analysis of the cavitation criterion. The SolidWorks flow simulation is described more in-depth in [Criterion analysis-Cavitation](#), *Chapter 3.3: Setup (see Appendix K)*. The only relevant goal for the simulation is the volume flow rate through the outlet. After the simulation criteria was set up correctly, 11 simulations were conducted, 1 for each 10% of opening. The results from these simulations where then compared and plotted in a graph which was used to rate the concepts.

As mentioned the simulation may provide irregularities in the results that is clearly wrong. These results may be overlooked if rerunning the simulation don't fix the issue.

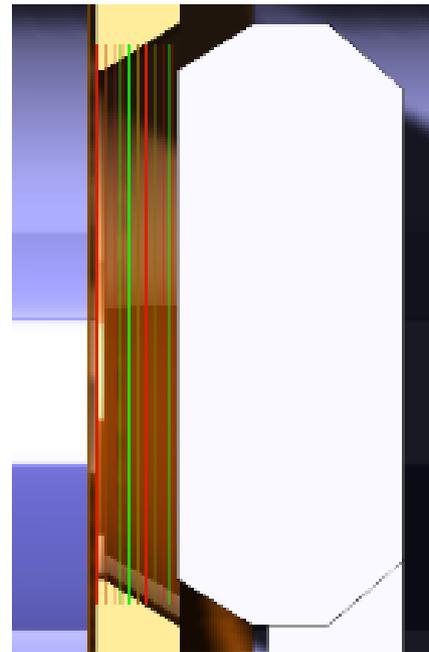


Figure 232: Planes in SolidWorks

5 Simulations

In this chapter the simulations for each concept are presented. It contains a figure showing the planes that were used to simulate the opening percentage, the numbers received from the simulations, a graph of these numbers and an evaluation of the results.

5.1 Concept 1: Bucket

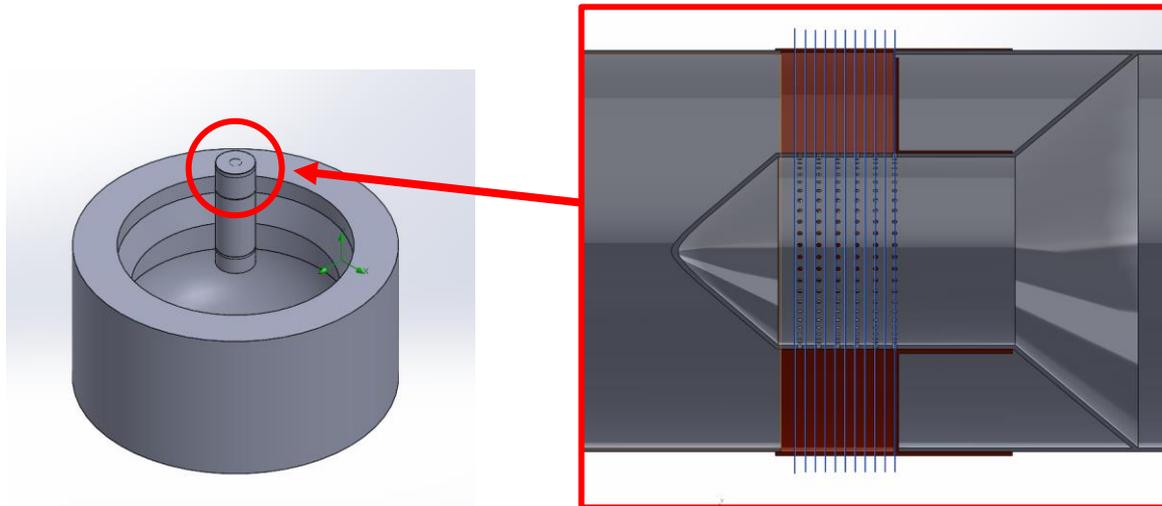


Figure 233: Concept-1 with the regulatory steps highlighted. The valve used is the same as in concept 7

The evaluation of the bucket concept will be related to the concept 7. The idea is to look at the possibility to combine a dissipation device with control valve. The flow characteristic criterion is related to flow regulation. For that reason, the control valve is the system of interest. The criterion score will be presented here as well, but the evaluation can be found in subchapter 5.7.

Criterion score: **4**

5.2 Concept 2: Movable pipe 1

5.2.1 Regulation steps

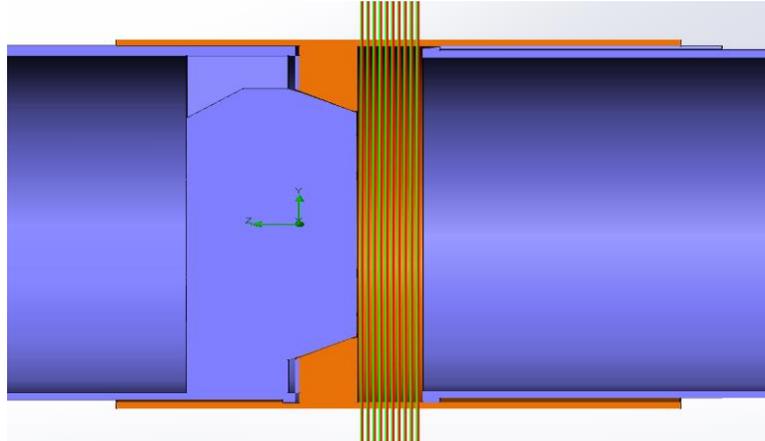


Figure 234: Illustration of the regulation steps in concept 2

5.2.2 Table

Opening	100 %	90 %	80 %	70 %	60 %	50 %	40 %	30 %	20 %	10 %	0 %
Flow rate[m ³ /s]	8,57	7,91	6,97	5,77	5,02	4,29	3,51	2,67	1,08	0,41	0

Table 105: Volume flow rate for every tenth percent opening in concept 2

5.2.3 Graph

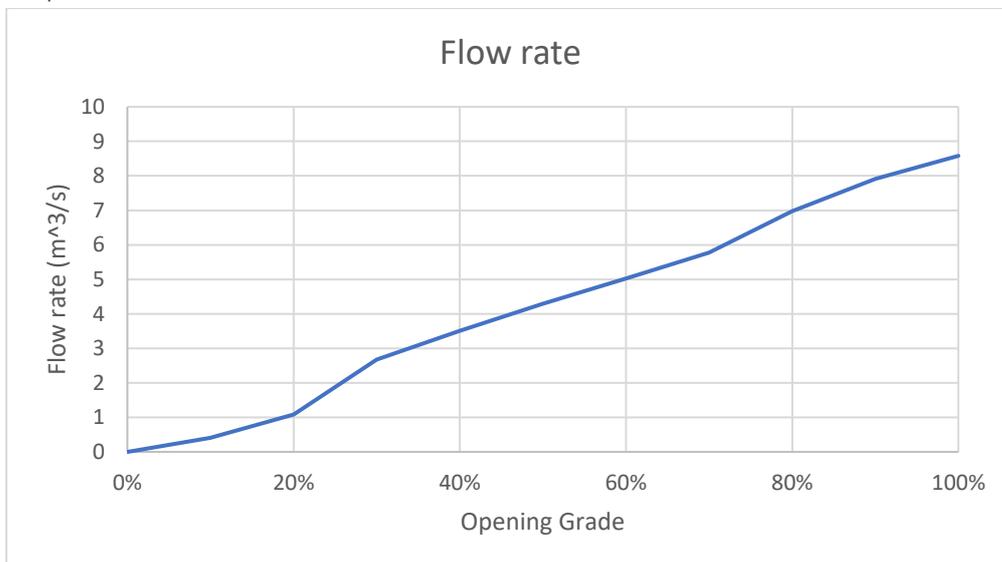


Figure 235: Graph illustrating the relation between opening and flow rate in concept 2

5.2.4 Evaluation

The movable pipe 1 illustrates almost a perfect linear flow characteristic. The simulation has no deviation or irregularities, so the group can conclude that the results are realistic. An equal percentage flow characteristic is preferred which is not the case here. Nevertheless, the concept shows high potential and that it can control flow in a desired way.

Criterion score: 6

5.3 Concept 3: Jet valve

5.3.1 Regulation steps

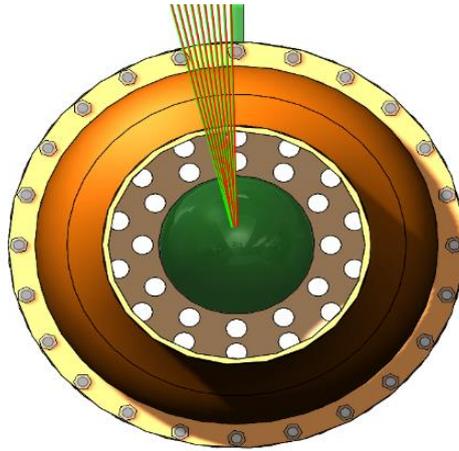


Figure 236: Regulatory steps in Concept: Jet valve

5.3.2 Table

Opening	100 %	90 %	80 %	70 %	60 %	50 %	40 %	30 %	20 %	10 %	0 %
Flow rate[m ³ /s]	3,17	3,12	3,15	4,27	2,90	3,23	1,75	1,35	0,97	0,79	0,31

Table 106: Volume flow rate for every tenth percent opening in concept 3

5.3.3 Graph

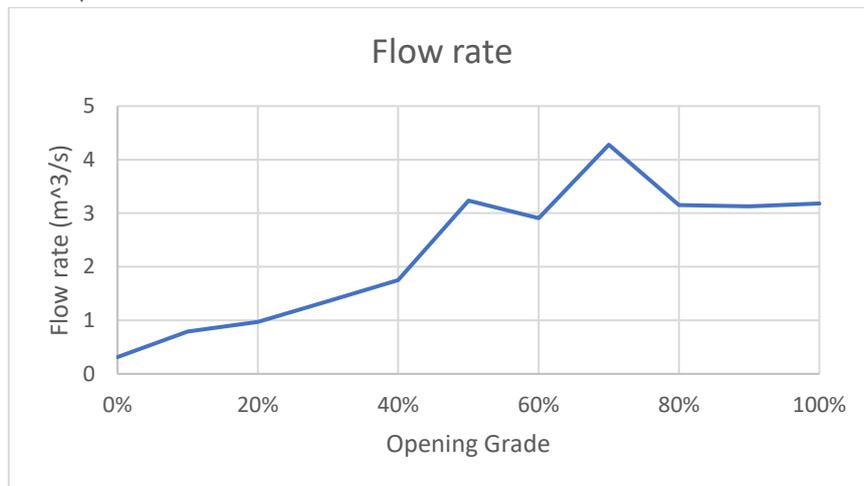


Figure 237: Graph illustrating the relation between opening and flow rate in concept 3

5.3.4 Evaluation

The graph illustrates a result that relates to a linear flow characteristic. Between 50% and 80% opening there are some irregular values that present a drop-in flow rate between 50-60% and 70-80%. This may be due lack of accuracy in the mesh or uneven design. To conclude the simulation, the jet valve shows an intended flow regulation even though the result is a little bit irregular.

Criterion score: 5

5.4 Concept 4: Movable pipe 2

5.4.1 Regulation steps

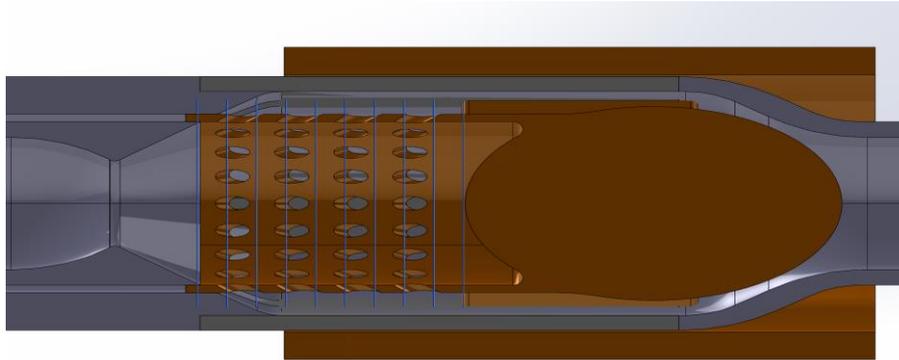


Figure 238: Illustration of the regulation steps in concept 4

5.4.2 Table

Opening	100 %	90 %	80 %	70 %	60 %	50 %	40 %	30 %	20 %	10 %	0 %
Flow rate[m ³ /s]	24,78	26,13	27,40	26,53	26,31	25,89	25,63	21,83	22,18	8,41	0,02

Table 107: Volume flow rate for every tenth percent opening in concept 4

5.4.3 Graph

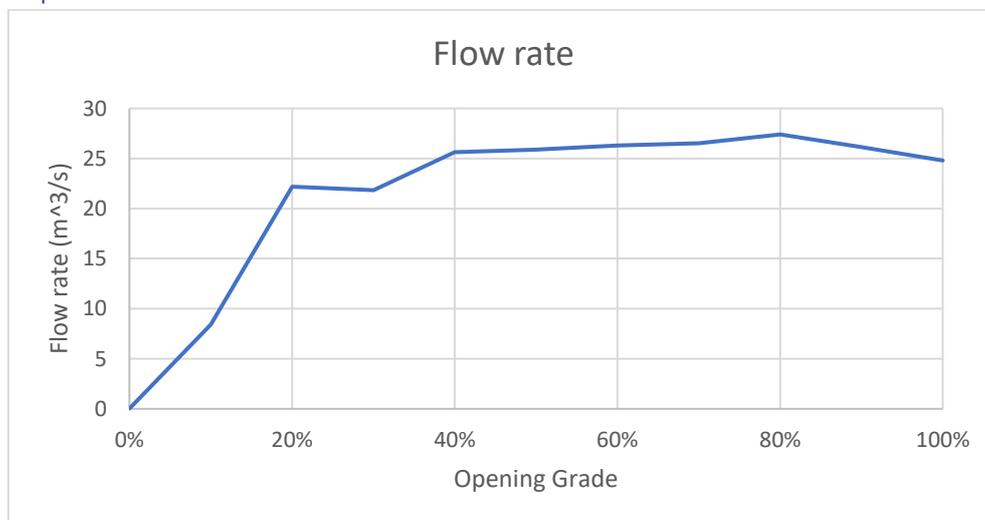


Figure 239: Graph illustrating the relation between opening and flow rate in concept 4

5.4.4 Evaluation

The movable pipe 2 shows a graph that may resemble a quick-opening flow characteristic. From closed position to 40% opening it has a linear characteristic, but from 40% to fully open it flattens out. From 20% to 30% there is a slightly drop in flow rate which most likely is an inaccuracy in the simulation. The concept shows that it can control flow and it may be optimized, but at this point it doesn't show a fully desired result.

Criterion score: 3

5.5 Concept 5: Energy dissipating box

5.5.1 Regulation steps

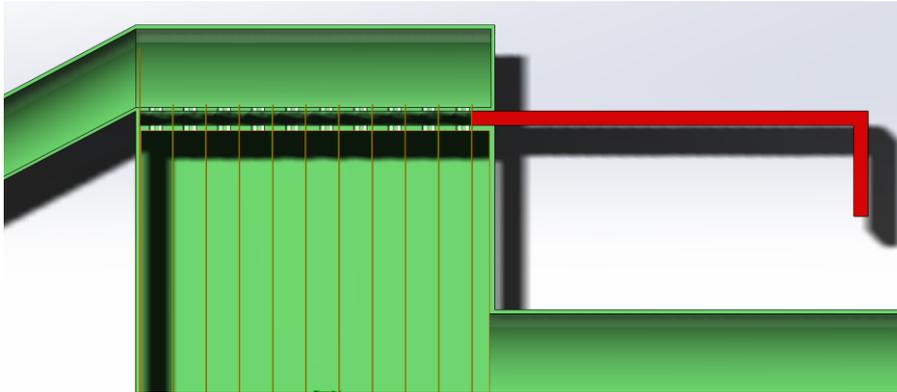


Figure 240: Illustration of the regulation steps in concept 5

5.5.2 Table

Opening	100 %	90 %	80 %	70 %	60 %	50 %	40 %	30 %	20 %	10 %	0 %
Flow rate[m ³ /s]	37,41	36,96	36,46	35,39	33,80	32,03	27,50	21,92	16,41	7,59	0

Table 108: Volume flow rate for every tenth percent opening in concept 5

5.5.3 Graph

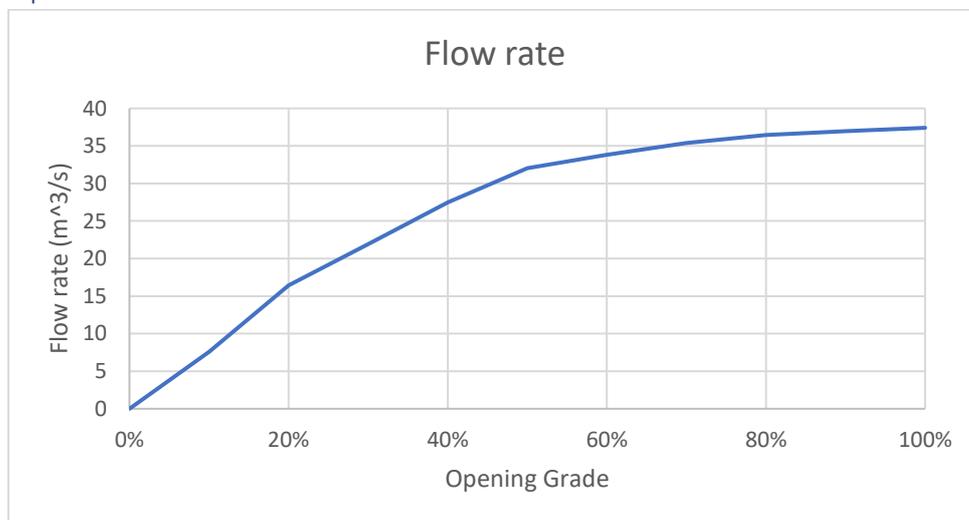


Figure 241: Graph illustrating the relation between opening and flow rate in concept 5

5.5.4 Evaluation

The Energy Dissipating box has a flow characteristic between linear and quick opening. The flow is increasing almost linearly up to 50% opening, and then the rate of change in flow rate is decreasing. With a few changes to the design this valve can easily achieve a linear characteristic.

Criterion score: 4

5.6 Concept 6: Plug

5.6.1 Regulation steps

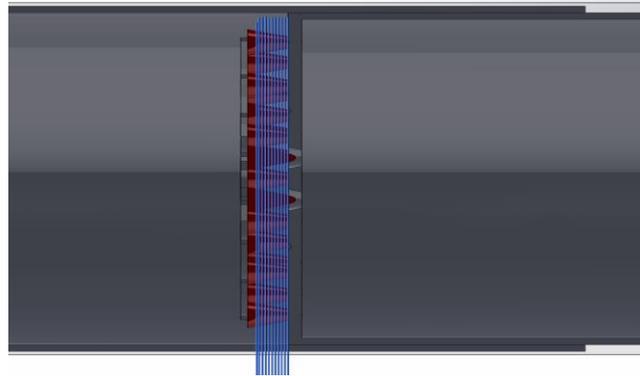


Figure 242: Illustration of the regulation steps in concept 6

5.6.2 Table

Opening	100 %	90 %	80 %	70 %	60 %	50 %	40 %	30 %	20 %	10 %	0 %
Flow rate[m ³ /s]	0,34	0,25	68,36	61,84	62,00	62,42	62,92	62,96	63,15	62,94	1,87

Table 109: Volume flow rate for every tenth percent opening in concept 6

5.6.3 Graph

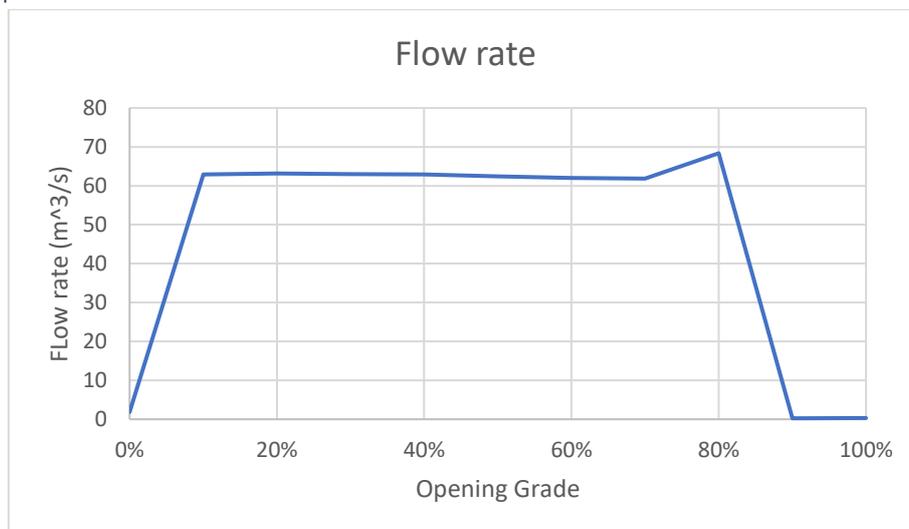


Figure 243: Graph illustrating the relation between opening and flow rate in concept 6

5.6.4 Evaluation

Looking at the results from the simulation of concept 6, the group sees no sign of any desired flow regulation. From closed position to 10% opening the flow rate drastically increases, and between 10% and 80% opening, the results show no change in flow rate. It should be mentioned that concept have had some peculiar results in the cavitation as well. It may be because of the simulation or design-faults, but if the group can't get any clear results it's not possible give a good evaluation.

Criterion score: 1

5.7 Concept 7: Movable pipe 3

5.7.1 Regulation steps

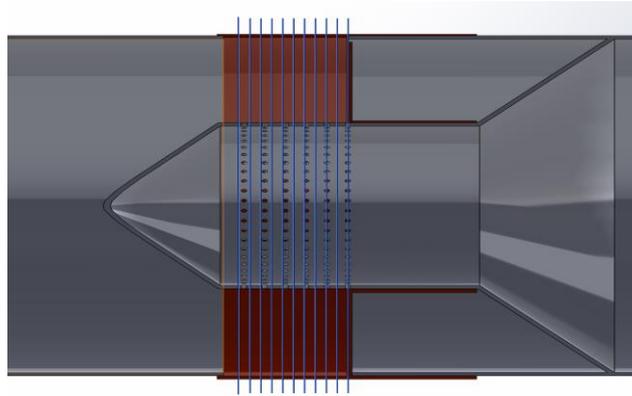


Figure 244: Illustration of the regulation steps in concept 7

5.7.2 Table

Opening	100 %	90 %	80 %	70 %	60 %	50 %	40 %	30 %	20 %	10 %	0 %
Flow rate[m ³ /s]	7,02	6,71	5,07	5,67	5,46	5,07	4,65	4,19	3,39	3,31	0

Table 110: Volume flow rate for every tenth percent opening in concept 7

5.7.3 Graph

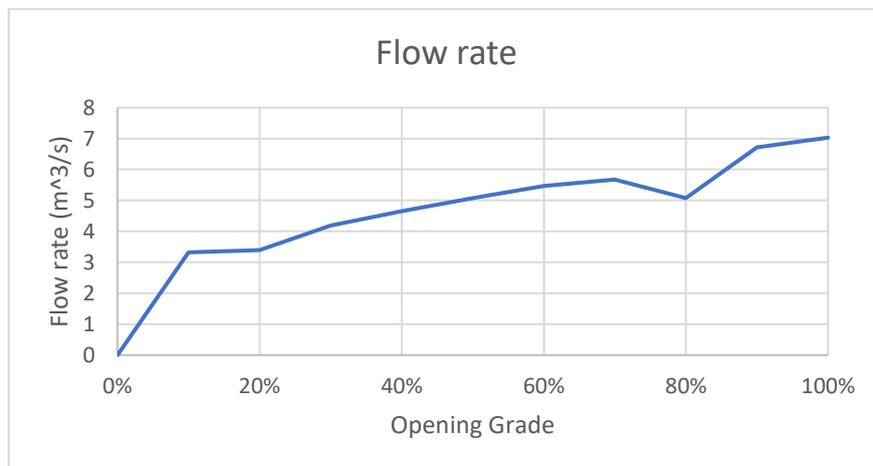


Figure 245: Graph illustrating the relation between opening and flow rate in concept 7

5.7.4 Evaluation

The flow characteristic of concept 7 may resemble a combination between linear- and quick opening characteristic, if you look away from the deviation at 10% and 80%. The grade of opening is close to proportional to the rate of flow. To conclude, the simulation illustrates an operation that fulfills the criterion in a good manner.

Criterion score: 5

5.8 Concept 8: Rock Block

5.8.1 Regulation steps

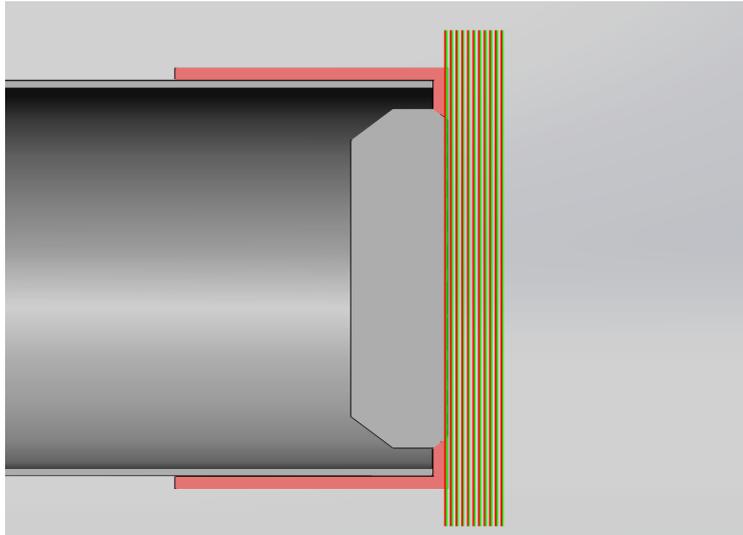


Figure 246: Illustration of the regulation steps in concept 8

5.8.2 Table

Opening	100 %	90 %	80 %	70 %	60 %	50 %	40 %	30 %	20 %	10 %	0 %
Flow rate	7,16	7,15	7,13	7,11	7,09	7,06	7,02	6,94	6,83	6,75	0

Table 111: Volume flow rate for every tenth percent opening in concept 8

5.8.3 Graph

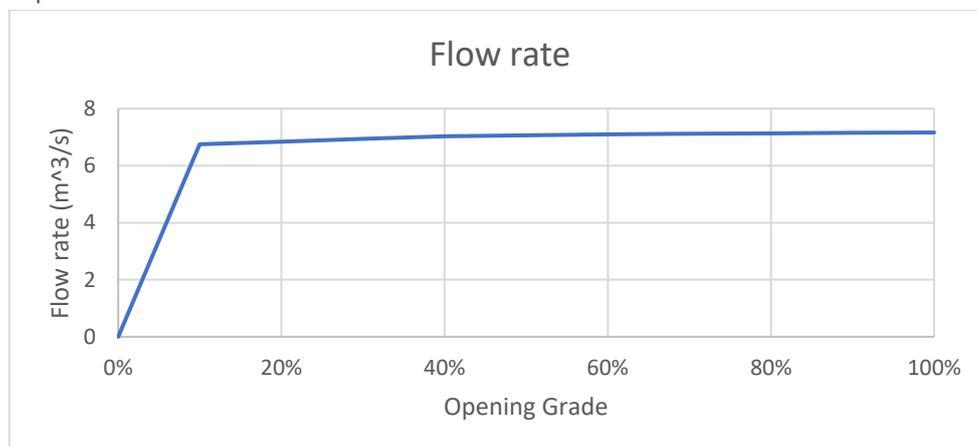


Figure 247: Graph illustrating the relation between opening and flow rate in concept 8

5.8.4 Evaluation

The simulation of the rock block concept gives an understanding that it can regulate flow to some extent. From closed position to 10% it has a radically increase in flow rate and then it flattens out. A possibility can be that the spacing in the regulation steps is too large. Either way the concept has a lack in the ability to regulate the flow.

Criterion score: 2

5.9 Concept 9: Rotary cylinder

5.9.1 Regulation steps

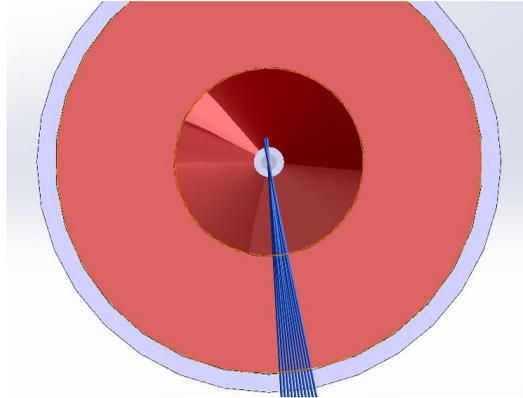


Figure 248: Illustration of the regulation steps in concept 9

5.9.2 Table

Opening	100 %	90 %	80 %	70 %	60 %	50 %	40 %	30 %	20 %	10 %	0 %
Flow rate[m ³ /s]	3,43	3,12	2,45	2,67	2,41	2,01	2,11	2,05	2,78	1,8	0

Table 112: Volume flow rate for every tenth percent opening in concept 9

5.9.3 Graph

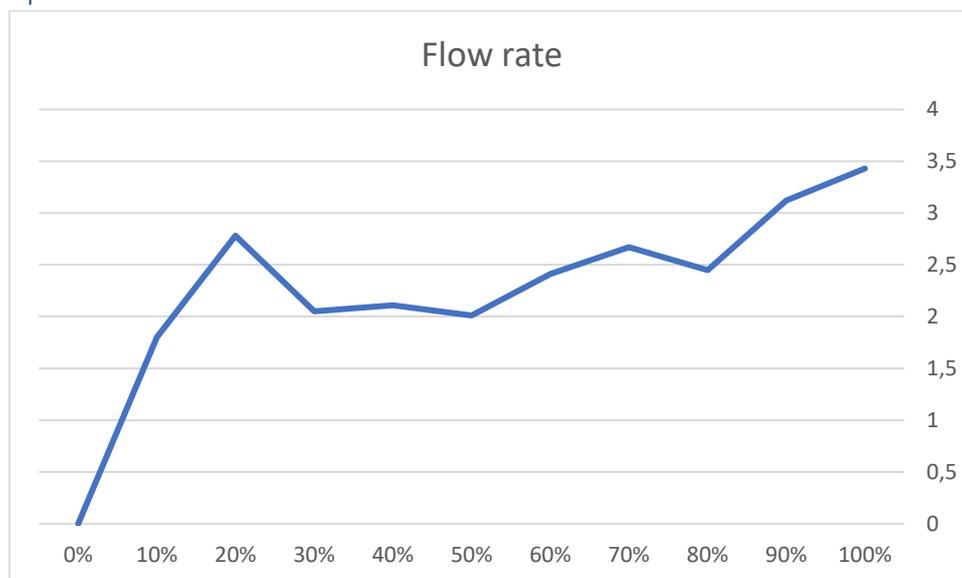


Figure 249: Graph illustrating the relation between opening and flow rate in concept 9

5.9.4 Evaluation

The graph shows that it is not a clear correlation between the flow rate and the opening. These results can come from an insufficient mesh in the simulations. The design can also be altered to achieve a better graph, but at this stage it will require significant work. Therefore, the design will receive a score of 3.

Criterion score: 3

5.10 Concept 10: Maze

5.10.1 Regulation steps

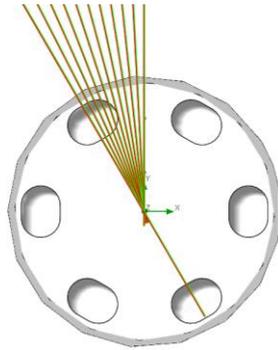


Figure 250: Illustration of the regulation steps in concept 10

Regulation steps

Opening	100 %	90 %	80 %	70 %	60 %	50 %	40 %	30 %	20 %	10 %	0 %
Flow rate[m ³ /s]	3,43	3,12	2,45	2,67	2,41	2,01	2,11	2,05	2,78	1,8	0

Table 113: Volume flow rate for every tenth percent opening in concept 10

5.10.2 Graph

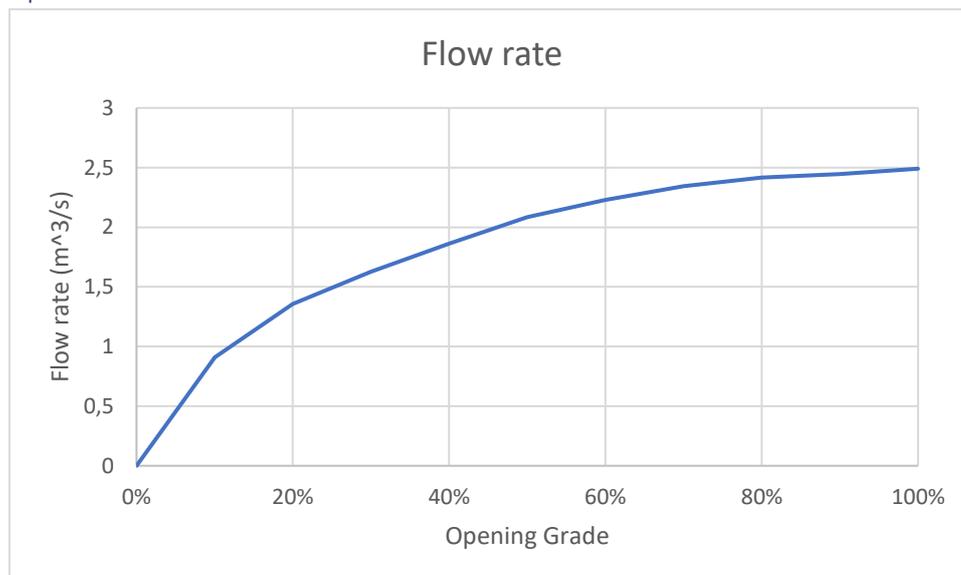


Figure 251: Graph illustrating the relation between opening and flow rate in concept 10

5.10.3 Evaluation

The result from the maze show a fine and coherent graph. It illustrates a flow characteristic which looks like a combination of a linear- and quick opening characteristic. The simulation has no deviations or irregularities. To evaluate the concept, the group sees a concept with good potential and a desired flow regulation. Optimization of the concept may improve the flow characteristic even more.

Criterion score: 5

6 Summary

In the table below the results from the simulations can be viewed. The full simulations can be found in *Chapter 5*. Concept 2 scores the best because it shows the most potential. The worst is Concept 6 because the reduction in flow rate occurs between 10 and 20% of maximum opening. And thus, it will be difficult to control the flow accurately.

Concept	Score
Concept 1: Bucket	4
Concept 2: Movable pipe 1	6
Concept 3: Jet valve	5
Concept 4: Movable pipe 2	3
Concept 5: Energy dissipating box	4
Concept 6: Plug	1
Concept 7: Moveable pipe 3	5
Concept 8: Rock block	2
Concept 9: Rotary cylinder	3
Concept 10: Maze	5

Table 114: Results from the grading

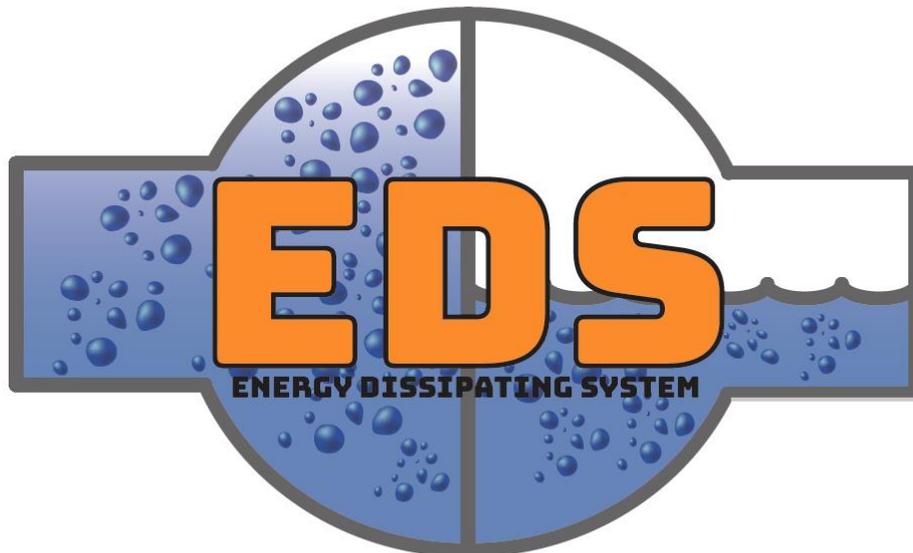


Multiconsult

Design of bypass valve

Appendix K: Criterion analysis – Cavitation

22.05.2018



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Abstract

Background: The selection process for the concepts will be completed using a Pugh matrix with several criteria. This document will evaluate the criterion, cavitation.

Method: The evaluation of cavitation is done using the add-in, Flow simulation, on SolidWorks. By defining the test with the operational parameter given in the system requirements, the group can simulate and predict cavitation. Relevant plots will be presented from simulations of each concept. By looking at the intensity and location of cavitation, a grade from 1-6 will be set.

Result: The concept which got the highest score and thus shows the most potential is the bucket concept. On the other hand, the rotary cylinder and plug got a score of 1 and thus shows the least potential.

Document history

Version	Date	Author	Description
0.00	27.02.18	OO	<ul style="list-style-type: none"> Created the document
0.01	29.02.18	OO	<ul style="list-style-type: none"> Added results from all concepts
0.02	02.02.18	OO	<ul style="list-style-type: none"> Added new results and removed the old ones Added introduction and Flow analysis chapters.
0.03	07.03.2018	LH	<ul style="list-style-type: none"> Proofreading
0.04	08.03.18	JS	<ul style="list-style-type: none"> Added cavitation phenomena chapter
0.05	08.03.18	OO, LH, JS, MH	<ul style="list-style-type: none"> Updated evaluation and results
1.00	09.03.18	MH, JS	<ul style="list-style-type: none"> Proofreading + minor changes in the text.
2.00	19.05.18	OO	<ul style="list-style-type: none"> Proofread Changed reference setup

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1 Introduction

As part of the concept selection process the group is going to use a Pugh Matrix, and one of the criteria in this Pugh-matrix is cavitation. Technical documents and simulations are needed to evaluate this phenomenon. These simulations will be presented in this document with an evaluation of the concepts and a score from 1-6. The document will also briefly go through the setup of the simulation, desired results and how the simulation is related the system requirements.

1.1 Cavitation phenomenon

1.1.1 Physical origin

Water can change phase according to the variation of temperature, at atmospheric pressure it freezes at 0°C and boils at 100°C. Each pressure has its individual temperature of phase change. The solidification temperature almost does not change for different pressures, but the vaporization pressure has a high dependency with temperature. Therefore, at very low pressures the water boils at a lower temperature. For example, at 2.33 Pa (0.0231 atmospheric pressure) the water boils at 20°C (Lide, 2004, pp. 6-8). The cavitation is a phenomenon, which can occur at room temperature when the pressure gets very low in the liquid, and so, transform it into vapor. The pressure at where the fluid becomes vapor is defined as the vapor pressure.

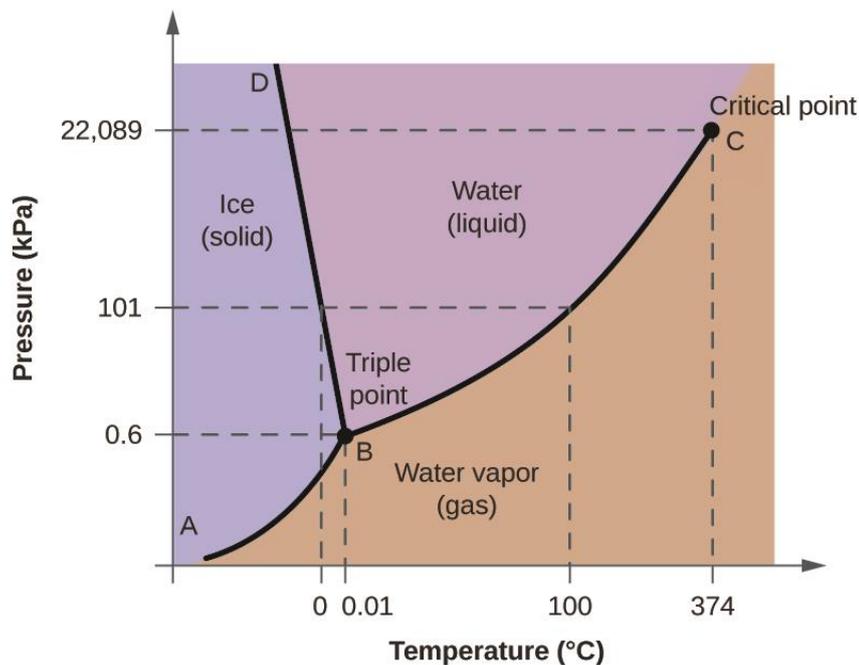


Figure 252: Phase diagram of water. The different regions are the three phases of matter, and the black lines are the phase changes (Creative Commons, 2012)

1.1.2 Influence on turbomachinery design

Cavitation is one of the most important design criterion in turbomachinery. When the vapor bubbles get into a high-pressure zone, the difference of pressure, between the open area and the region between the bubble and the wall, produces an implosion. The bubble implosion causes a small jet against the surface (Figure 254). This jet can cause damage to the wall. Even though one jet will not do much harm, the damage will accumulate over time to a serious problem. These jets are producing erosion and removing the corrosion protection, which is very important on metallic surfaces in contact with water.

The general cavitation criterion is avoiding cavitation, and if it happens, it must be far away from solid surfaces or happen on replaceable parts. However, there are some materials prepared to handle some levels of cavitation, but they are, in general, expensive.



Figure 253: Turbine damaged by cavitation (MCOR, 2016)

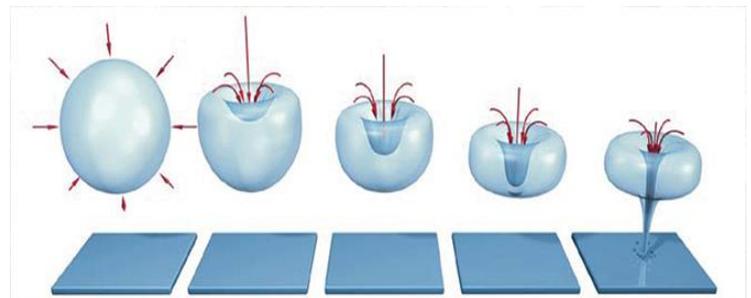


Figure 254: Evolution of the micro jet in a bubble collapse (MCOR, 2016)

2 Flow analysis

In this chapter, the group will explain how the SolidWorks Flow Simulation tool is used, the setup of each concept and how to interpret the results. It is important to document all the parameters used to ensure that the group can replicate the simulation if need be. The relation between the system requirements and the simulations will also be discussed.

2.1 SolidWorks flow simulation tool

Flow simulation is one of many add-ins in SolidWorks. It gives the opportunity to determine the impact of liquid and gas flow inside or outside a model. Liquid, or more specified water, is a central element in the project. Flow analysis will then be an essential tool for the execution of the project.

2.2 Ansys Fluent

Another flow analysis tool the group can use is Ansys Fluent. Fluent is a more complex program which requires a lot more parameters and preparation of the model, which is a time-consuming process. At this point, the group has ten roughly designed models and are not interested in detailed results, but more interested in comparable results. SolidWorks Flow Simulation, on the other hand, is a more straightforward flow analysis tool that is easier to setup and does not require so much time. Therefore, SolidWorks flow simulation has been used in the concept analysis. Fluent will be used when the concept selection is complete and when the concentration on optimizing the system begins.

2.3 Setup

This subchapter will contain a description of the setup of the simulation.

2.3.1 Preparation of the model

Before running the simulation, the cavity in the model must not have any openings. In other words, the model must be watertight. This is achieved by creating “lids”, which closes the open surfaces. Usually the inlet and outlet are the only parts that need closing, but for example, with the bucket and rock block concepts, the group had to make comprehensive changes to get comparable results. These changes will be described in the test chapter for each of them.

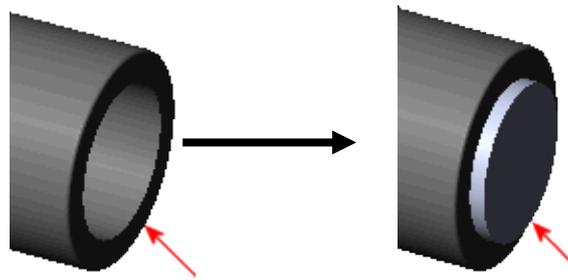


Figure 255: illustration of a lid

2.3.2 Boundary conditions

Boundary conditions are applied to the inlet and outlet of the concept. SolidWorks offers the opportunity to either choose volume flow, velocity, mass flow or pressure. The inlet pressure is specified in the system requirements as 30 bar, which correlates to 300-meter water column. The outlet will be set to an environmental pressure approximately equal to one bar. The volume flow through the valve can be measured by using surface goals (*Chapter 2.3.4*). Figure 5 illustrates how the boundary condition *looks like when applied on a lid*.

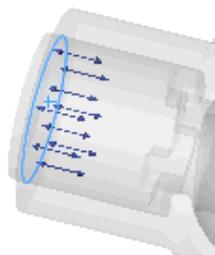


Figure 256: Illustration of a boundary condition defined on a lid surface

2.3.3 Mesh

A mesh can simply be described as splitting the model into tiny blocks, as illustrated in figure 6. When simulating the model, the program will look at how the forces are transferred between these blocks. A finer mesh will result in smaller blocks, a significantly longer simulation time but more detailed results. At this point, the group is more interested in a comparable result than a detailed one. Seeing as this is a time-consuming process, the group does not have time to use several hours simulating each of the concepts. This is why the standard mesh with no inserted local mesh is chosen.

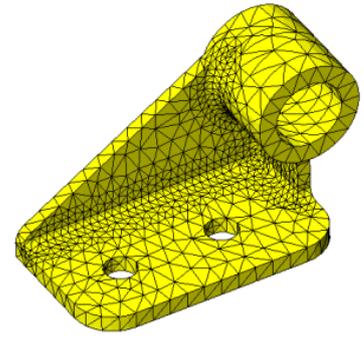


Figure 257: Illustration of a mesh

2.3.4 Goals

The goals in SolidWorks flow simulation are parameters that will be monitored. The simulation is an iterative process, where the simulations will run until the calculated values from the previous iteration is equal to the current one. By specifying goals, SolidWorks will specifically monitor these values in the iterative simulation to get more accurate results. In the subchapter “Goal values”, for each concept the values from the simulation are presented and the goals are shown in Table 115. These values serve as an aid to understand the results. For example, if the volume flow rate in a concept is near $3 \text{ m}^3/\text{s}$, these values can be used as a comparable result to other concepts. If a concept has a volume flow ten times higher than intended it is most likely not comparable, but the location of the cavitation and flow characteristic can still be evaluated. The main objective of this analysis is to look at cavitation.

Goal Name	Unit	Why
Global Goal: Av Velocity	[m/s]	flow through vena contracta
Global Goal: Max Volume Fraction of Vapor	[]	Cavitation
Global Goal: Av Density	[kg/m ³]	Cavitation
Surface Goal: Volume Flow Rate	[m ³ /s]	Outlet volume flow
Surface goal: Av Velocity	[m/s]	Outlet volume flow

Table 115: Defined goal values for the simulations

The goals that are relevant for us is shown in Table 115. There are two kinds of goals, global- and surface goals. The global goal is a parameter for the whole model. These can either be max, min or average through the model. A surface goal focuses on the value at a specific surface, for example the outlet.

- Global goals
 - Average Velocity
 - This is specified to look at the average velocity through the whole model and compare it to the velocity through vena contracta³.
 - Max volume fraction of vapor
 - Varies from 0 to 1 where 1 indicates 100% vapor bubbles. Less is generally better. This goal is specified to easier see where cavitation is occurring.
 - Average density
 - A local drop in density can mean that cavitation is happening.
- Surface goals
 - Volume flow rate
 - The volume is specified at the outlet to observe how large the flowrate is through the valve. The goal is to have the volume flow rate close to 3 m³/s
 - Average velocity.
 - The average velocity should not be above 10 m/s, and it is thus necessary to monitor this value.

³ Vena contracta is the location in the model where the diameter is the smallest.

2.4 Results and how to evaluate them

When the simulation is solved, there are several ways to evaluate the results. The easiest way to explain the plots and how they are evaluated is to present a simple example. The example will be a pipe with a narrowing space in the middle, the vena contracta. The model will be prepared with lids and boundary conditions. When the simulation is solved the group will first look at a cut plot of the pipeline.

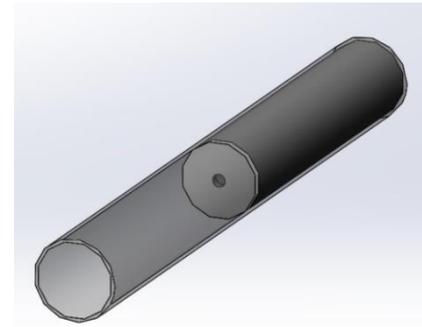


Figure 258: Example of a pipe with a narrow gap

2.4.1 Cut plot

The cut plot is a representation of the values of a given parameter through a cross-section of the simulated model. In this case, the group wants to look at where vapor is formed and what amount. In these places cavitation will occur. In Figure 259, the concentration of vapor is after the obstacle. When looking at the scale, it is easy to see that the numbers are quite high and the amount of vapor through vena contracta is large.

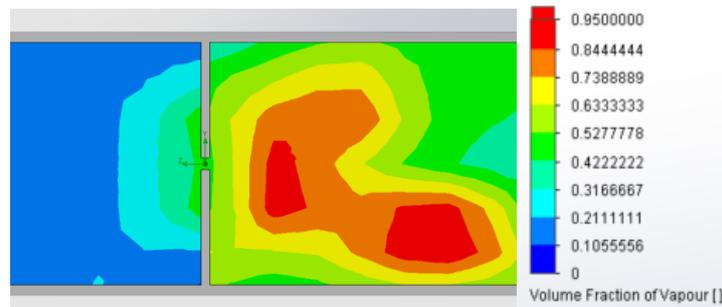


Figure 259: Example of a plot illustrating the volume fraction of vapor

2.4.2 Flow trajectory

The flow trajectory is another plot where the visual representation of the flow path is presented. The plot consists of several lines which represents the flow, the color represents the value of a given parameter. This is a great plot to evaluate if the water flow through the system is as expected. In this case the flow goes through the narrowing space as expected. The conclusion is that the results in the simulation are most likely correct.

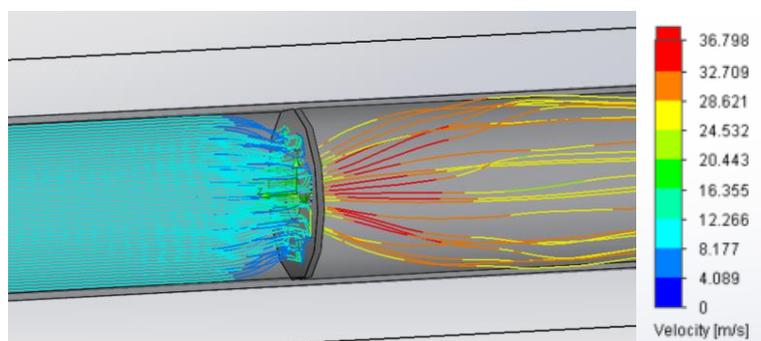


Figure 260: Example of a trajectory plot illustrating the velocity

2.4.3 Graph

The objective of the system is to dissipate energy and an excellent way to archive it is to force water through narrow spaces. Increased velocity will result in higher friction which, again, will result in higher energy dissipating. These narrow spaces are therefore an interesting section where the presences of cavitation must be evaluated. By drawing a line through vena contracta, a graph illustrating the presence of vapor can be made. In this case, the group has an exponential increase of vapor, and in the middle, the value is between 8-10% vapor which is a concerning value. The conclusion is that there most likely will occur cavitation in this area.

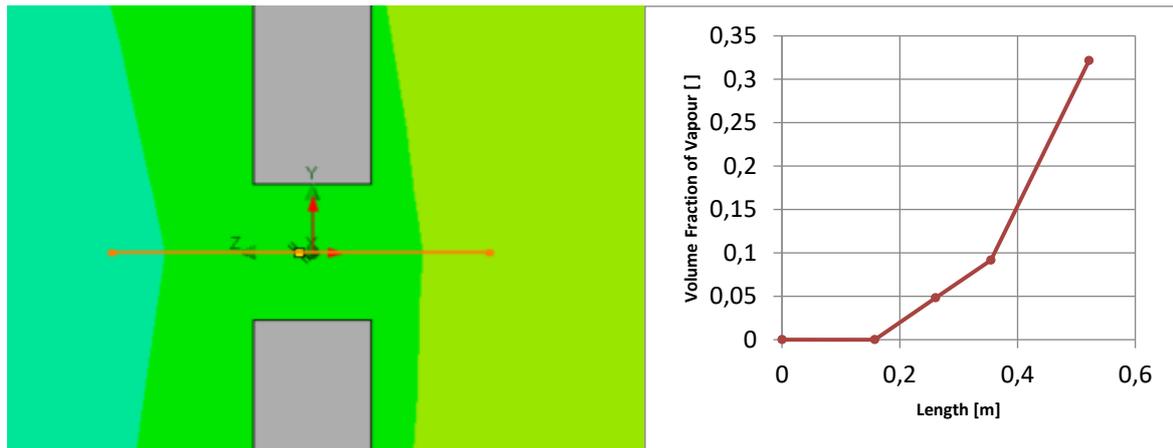


Figure 261: Example of a line through vena contracta and the graph showing the volume fraction of vapor through it

2.5 Criterion verdict

Cavitation in the concepts will be scored on two factors; “*Location of Cavitation*” and “*Degree of Cavitation*”, where the location is the most important one. If the cavitation is happening at a place where it does no damage the valve will receive the top score in both location and degree of cavitation. If the cavitation is occurring at a place it may do harm, the degree of cavitation must be considered.

Criteria	Score
Location of cavitation	A
Degree of cavitation	B
Total score	(A+B)/2

Table 116: Criterion evaluation

2.6 Related Requirements

The reason for these simulations is because they can be related to the system requirements. This subchapter will briefly explain how the requirements are related to completion of the simulation.

2.6.1 RQ-1

“The system MUST operate under the pressure of 150- to 300-meter water column.”

When defining the inlet condition, a water column of 300-meter is chosen, which relates to 30 bars.

2.6.2 RQ-2

“The system MUST operate with a flow rate up to 3 m^3/s ”

To get comparable results, one of the main focuses was to have dimensions that could result in a flow rate close as possible to 3 m^3/s . By manipulating the flow control mechanism, the desired flow rate could be achieved.

2.6.3 RQ-4

“The system MUST manage cavitation satisfactorily.”

The volume fraction of vapor will determine the degree of cavitation in this case.

3 Simulation and evaluation

3.1 Concept 1: Bucket

3.1.1 Goal values

Table 117: Goal Values for concept 1

Goal Name	Unit	Value
GG Max Volume Fraction of Vapor 1	[]	0,90716727
GG Av Velocity 1	[m/s]	1,094764258
SG Volume Flow Rate 1	[m ³ /s]	-3,582746959
SG Av Velocity 1	[m/s]	0,285571833

3.1.2 Results

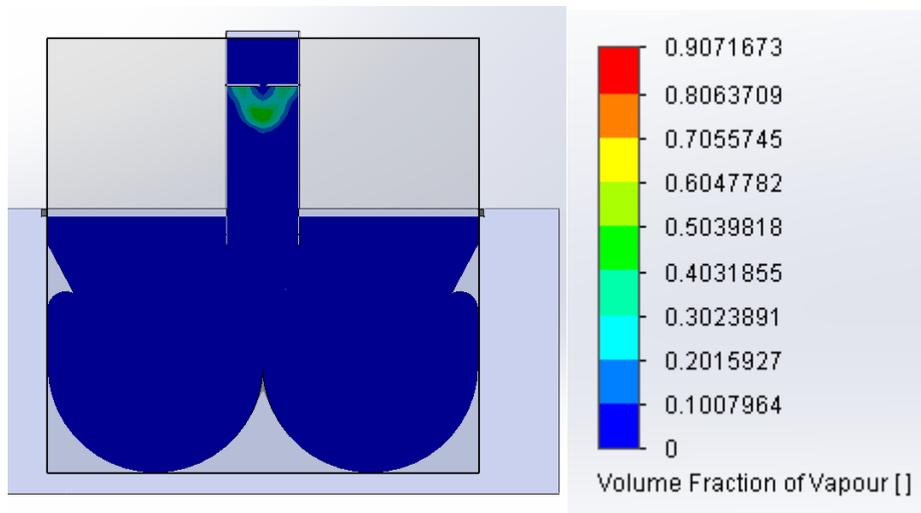


Figure 262: Plot of a cross-section illustrating the volume fraction of vapor in concept 1

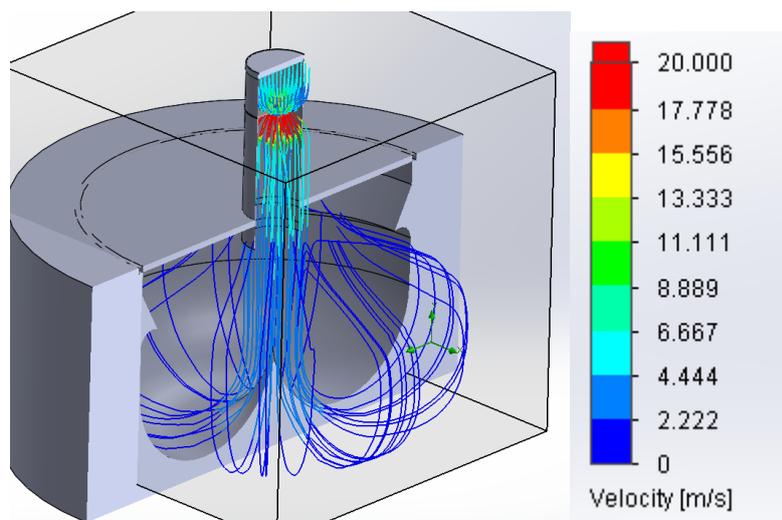


Figure 263: Trajectory plot illustrating the velocity in concept 1

3.1.3 Evaluation

The intended goal with the bucket is to add concept 7 at the top. So, when evaluating this concept, the data from concept 7 will be added.

Criteria	Score
Location of cavitation	6
Degree of cavitation	6
Total score	6

3.2 Concept 2: Movable pipe 1

3.2.1 Goal values

Table 118 Goal Values for concept 2

Goal Name	Unit	Value
GG Av Velocity	[m/s]	4,430326596
GG Max Volume Fraction of Vapor	[]	0,336520228
SG Volume Flow Rate	[m ³ /s]	-3,043300603
SG Av Velocity	[m/s]	3,926345507

3.2.2 Results

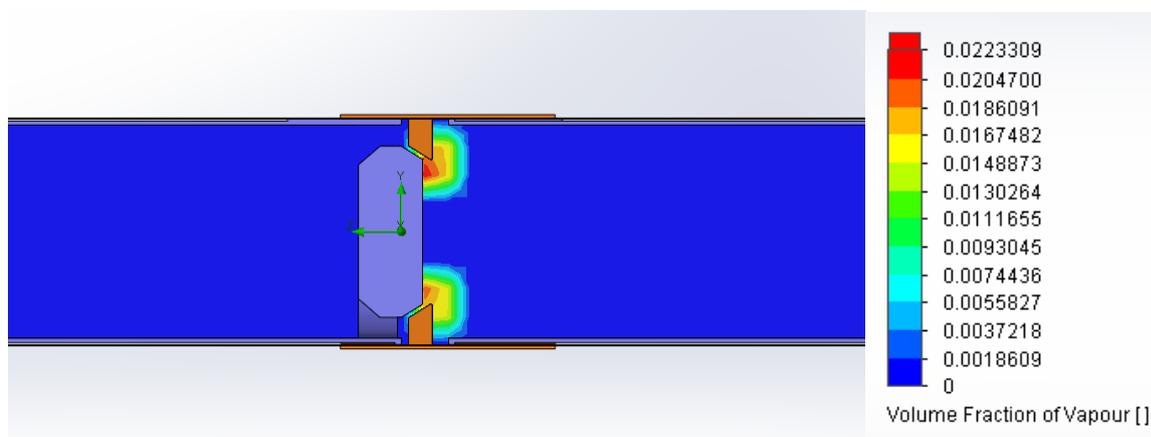


Figure 264: Plot of a cross-section illustrating the volume fraction of vapor in concept 2

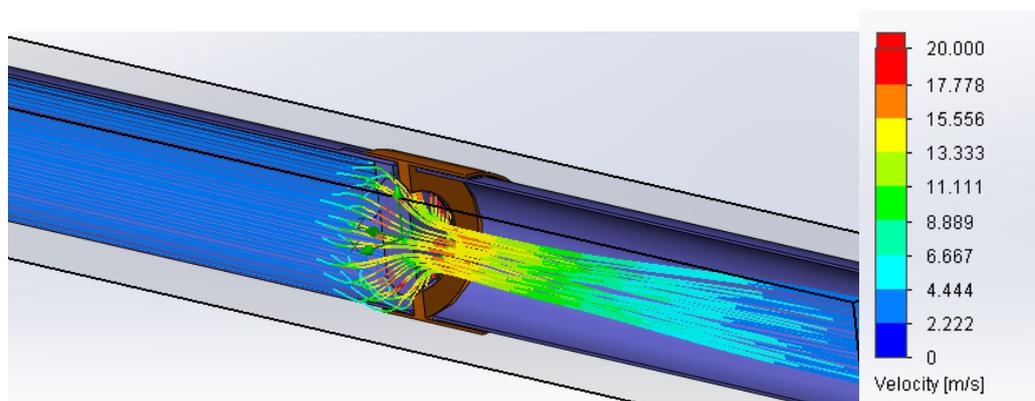


Figure 265: Trajectory plot illustrating the velocity in concept 2

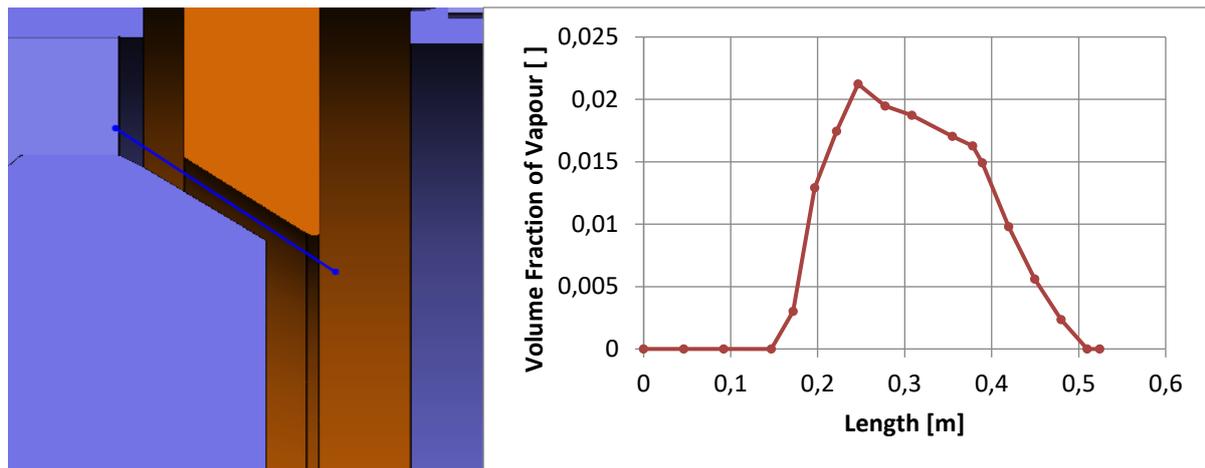


Figure 266: graph illustrating the volume fraction of vapor through vena contracta in concept 2

3.2.3 Evaluation

The simulation of the movable pipe gave a downstream volume flow close to $3 \text{ m}^3/\text{s}$, which is the desired value. When looking at the plot for the volume fraction of vapor, it's clear that cavitation is occurring right after the outlet of the valve. Cavitation occurring downstream was initially foreseen but having cavitation so close to the valve is unwanted. The flow trajectory plot of the velocity illustrates an intended and a proper flow path. Overall does the simulation show a design with potential, but the area of cavitation needs to be taken account fore in further development

Criteria	Score
Location of cavitation	3
Degree of cavitation	1
Total score	2

3.3 Concept 3: Jet valve

3.3.1 Goal Values

Table 119: Goal Values for concept 3

Goal Name	Unit	Value	Averaged Value
GG Av Velocity 1	[m/s]	4,125203881	4,136335024
GG Max Volume Fraction of Vapor 1	[]	0,09223252	0,119116426
SG Volume Flow Rate 1	[m ³ /s]	-3,281340536	-3,29442253
SG Av Velocity 1	[m/s]	4,649534942	4,638514233

3.3.2 Results

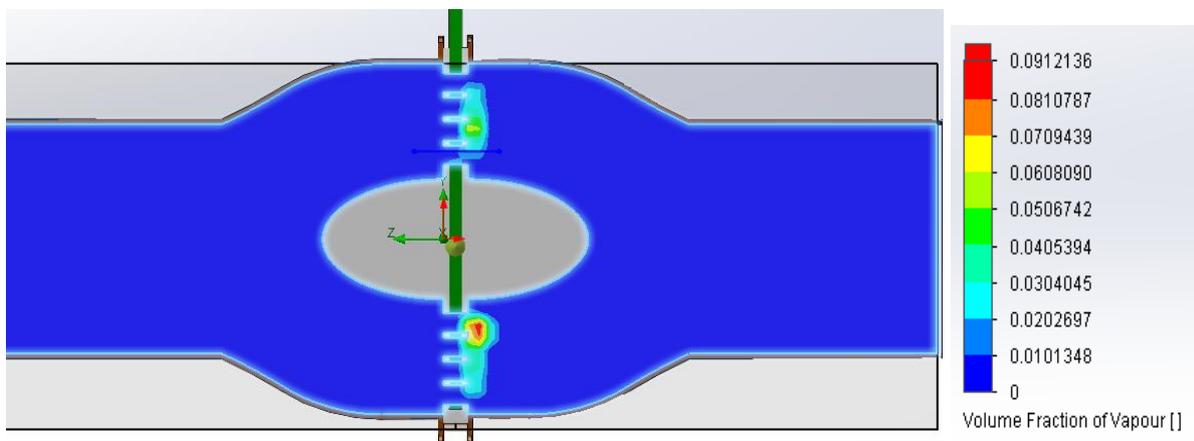


Figure 267: Plot of a cross-section illustrating the volume fraction of vapor in concept 3

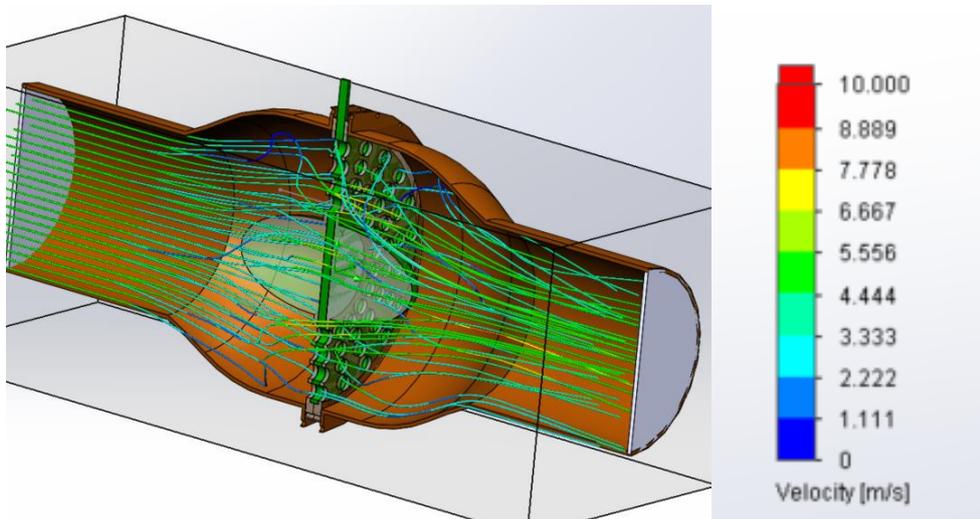


Figure 268: Trajectory plot illustrating the velocity in concept 3

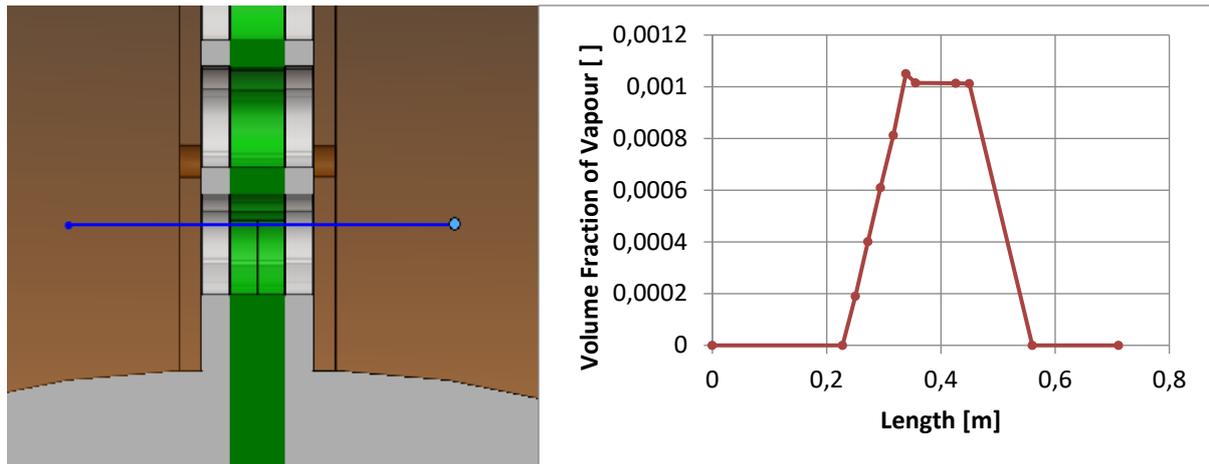


Figure 269: graph illustrating the volume fraction of vapor through vena contracta in concept 3

3.3.3 Evaluation

From the plots displayed above, it can be observed that the volume fraction of vapor is very low and the maximum in the plot is 0.01%. The volume flow rate with the valve fully opened is $3.2 \frac{m^3}{s}$ which is also perfect. Even though the degree of cavitation is low the location is concerning.

Criteria	Score
Location of cavitation	4
Degree of cavitation	2
Total score	3

3.4 Concept 4: Movable pipe 2

3.4.1 Goal Values

Table 120: Goal Values for concept 4

Goal Name	Unit	Value
GG Max Volume Fraction of Vapor 1	[]	0,95531488
GG Av Velocity 1	[m/s]	5,701677611
SG Volume Flow Rate 1	[m ³ /s]	-4,298143941
SG Av Velocity 1	[m/s]	6,241919294

3.4.2 Results

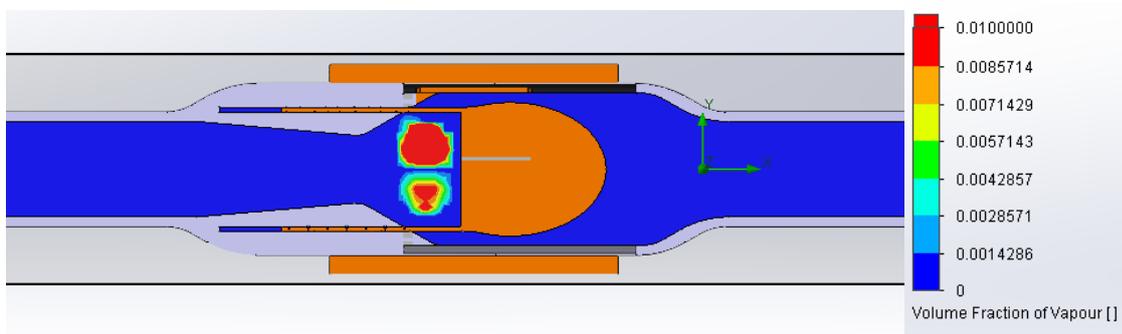


Figure 270: Plot of a cross-section illustrating the volume fraction of vapor in concept 4

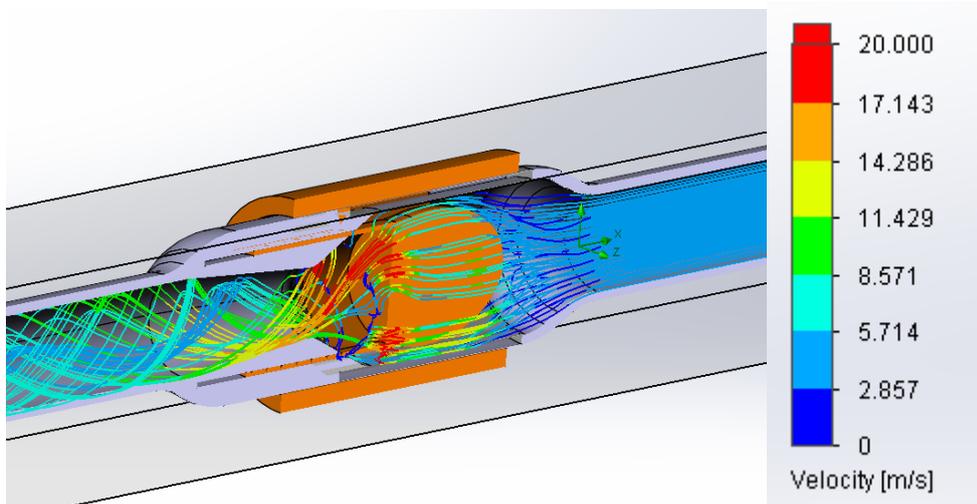


Figure 271: Trajectory plot illustrating the velocity in concept 4

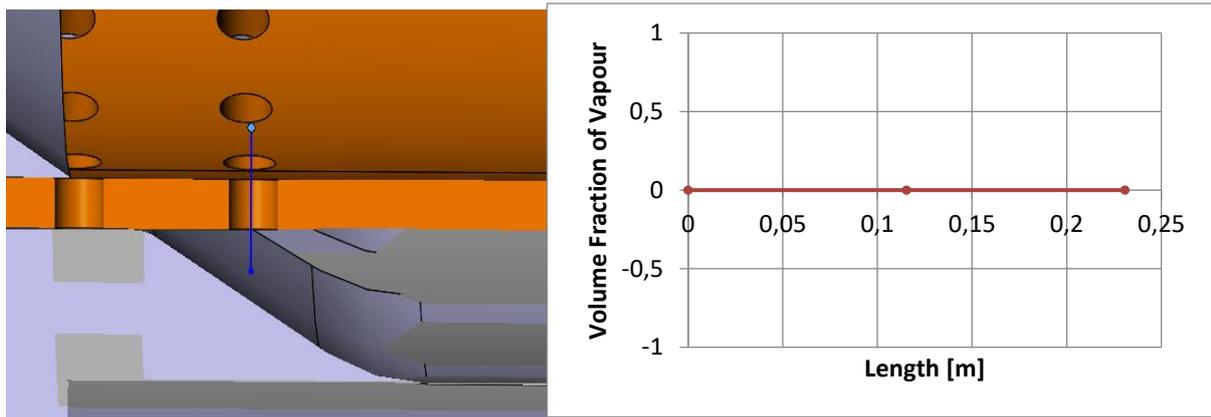


Figure 272: graph illustrating the volume fraction of vapor through vena contracta in concept 4

3.4.3 Evaluation

From the results, the volume fraction of vapor is maximum right after vena contracta. This is the place where cavitation will occur in this valve, but since this region is not in touch with any solid parts the cavitation is harmless. From the velocity plot, the valve creates turbulence downstream from the valve, which will help to dissipate energy. The volume flow rate is larger than the requirement and the valve could be optimized to be more cost efficient and still fulfill the requirements.

Criteria	Score
Location of cavitation	6
Degree of cavitation	5
Total score	5,5

3.5 Concept 5: Energy dissipating box

3.5.1 Goals values

Table 121: Goal Values for concept 5

Goal Name	Unit	Value
GG Av Velocity 1	[m/s]	14,23382836
GG Max Volume Fraction of Vapor 1	[]	0,954831384
SG Volume Flow Rate 1	[m ³ /s]	-15,32606424
SG Av Velocity 1	[m/s]	19,92170797

3.5.2 Results

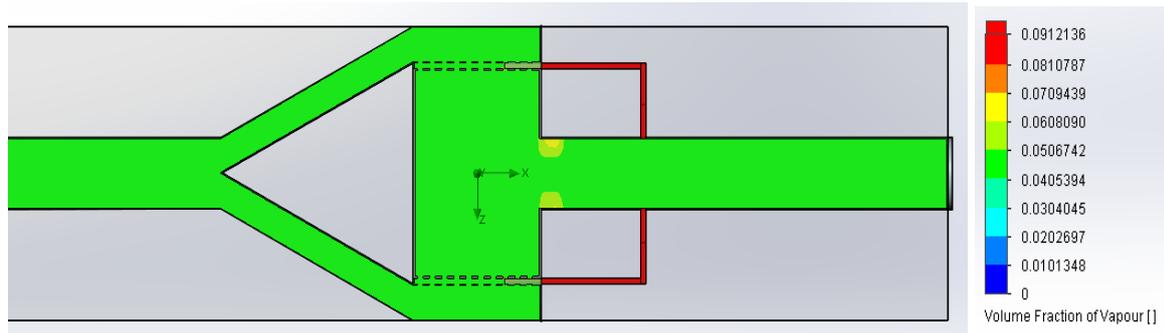


Figure 273: Plot of a cross-section illustrating the volume fraction of vapor in concept 5

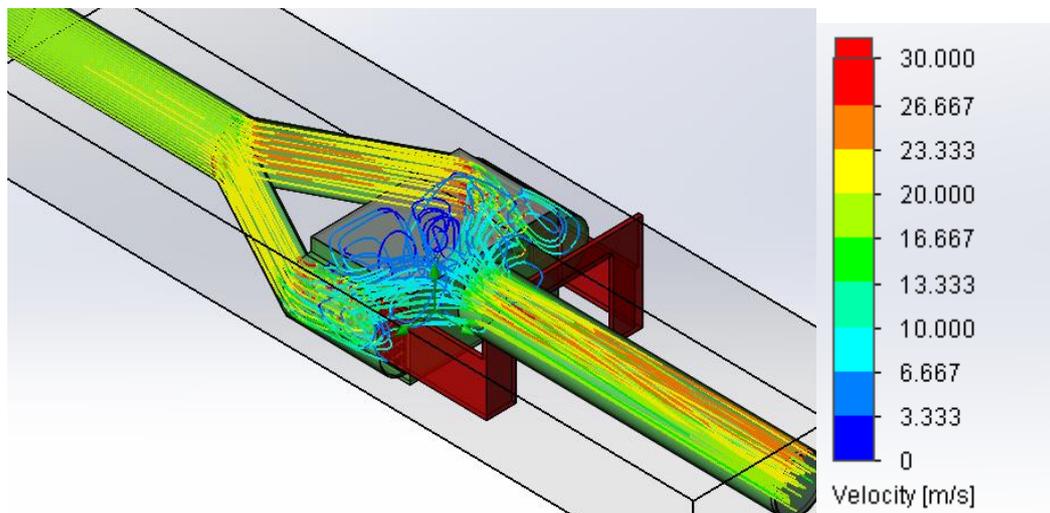


Figure 274: Trajectory plot illustrating the velocity in concept 5

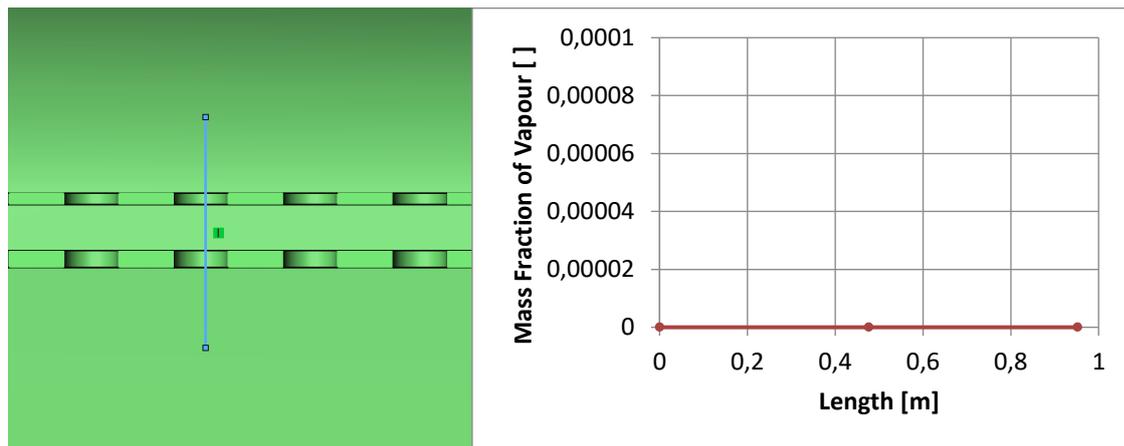


Figure 275: graph illustrating the volume fraction of vapor through vena contracta in concept 5

3.5.3 Evaluation

When looking at the volume fraction of vapor plot, a formation of vapor in the outlet pipe is spotted. Even though the values are low in this place, this needs to be taken into account. The flow trajectory shows the intended flow path. The water flow will be split into two smaller ones, and the velocity will increase until it reunites in the center of the box. In the outlet pipe, there is an increase in velocity again, and the values are a little bit higher than intended. The graph of the fraction of vapor shows that there is no cavitation occurring through vena contracta.

Criteria	Score
Location of cavitation	3
Degree of cavitation	3
Total score	3

3.6 Concept 6: Plug

3.6.1 Goal Values

Table 122: Goal Values for concept 6

Goal Name	Unit	Value
GG Max Volume Fraction of Vapor 1	[]	0,956848457
GG Av Velocity 1	[m/s]	30,50973309
SG Volume Flow Rate 1	[m ³ /s]	-28,89246971
SG Av Velocity 1	[m/s]	34,32407979

3.6.2 Results

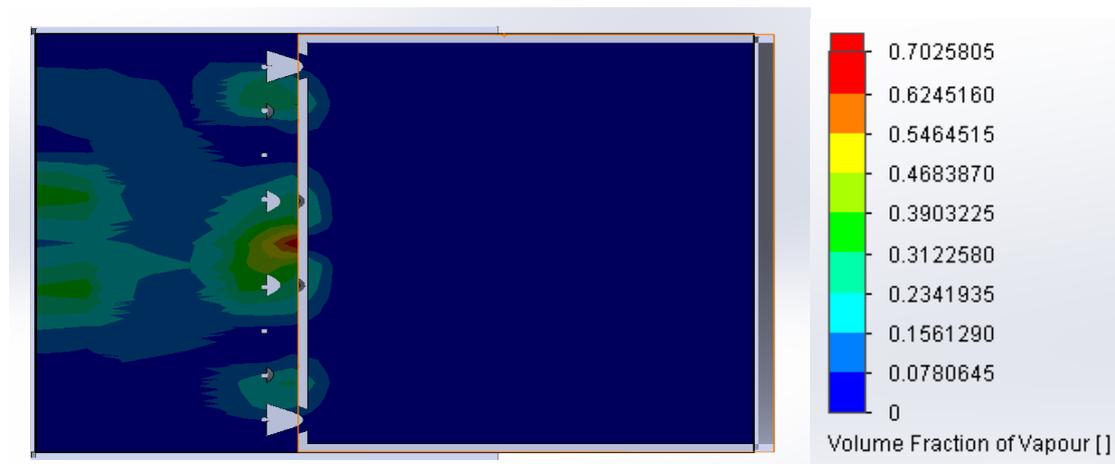


Figure 276: Plot of a cross-section illustrating the volume fraction of vapor in concept 6

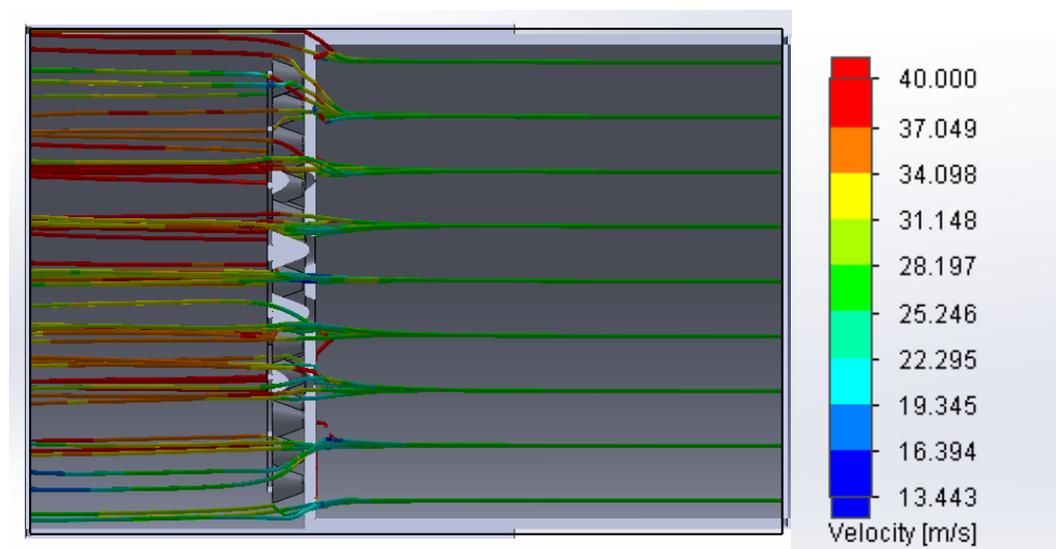


Figure 277: Trajectory plot illustrating the velocity in concept 6

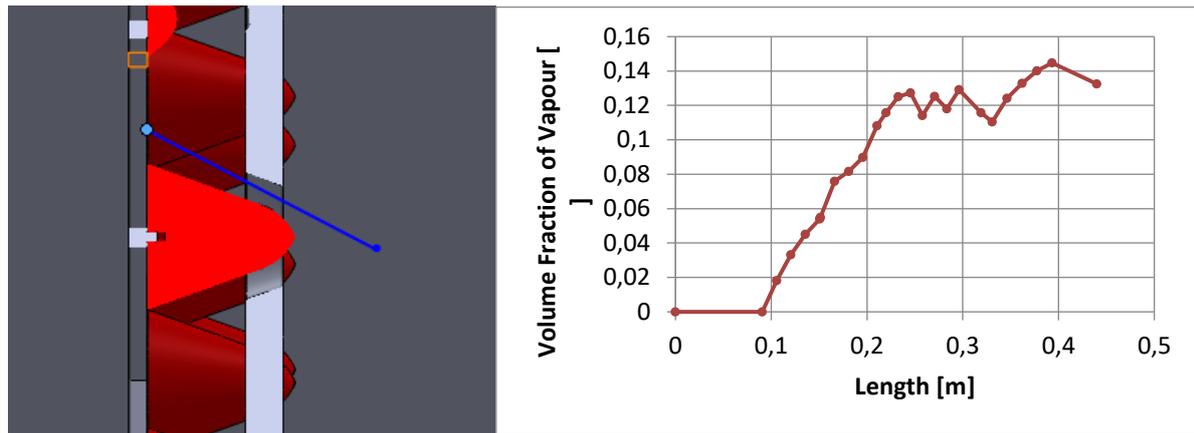


Figure 278: graph illustrating the volume fraction of vapor through vena contracta in concept 6

3.6.3 Evaluation

The mini pacifiers are a more experimental approach. The volume of vapor fraction is huge in the vena contracta and cavitation will occur here. In continued operation, the cavitation will create wear, and it will be destroyed. The volume flowrate tells us that the valve has optimization possibilities that, maybe, can address the cavitation problem caused by the high-pressure drop around the constriction in the flow. A multistage pressure drop could be a solution for this.

Criteria	Score
Location of cavitation	1
Degree of cavitation	1
Total score	1

3.7 Concept 7: Movable pipe 3

3.7.1 Goal Values

Table 123: Goal Values for concept 7

Goal Name	Unit	Value
GG Av Velocity	[m/s]	4,838542918
GG Max Volume Fraction of Vapor	[]	0,604248919
SG Volume Flow Rate	[m ³ /s]	-2,794331989
SG Av Velocity	[m/s]	3,765129989

3.7.2 Results

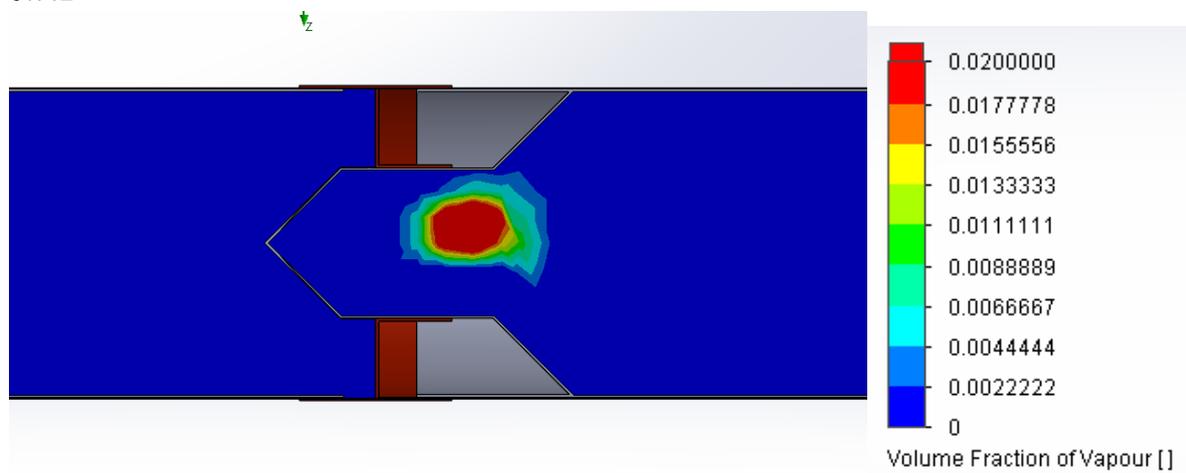


Figure 279:: Plot of a cross-section illustrating the volume fraction of vapor in concept 7

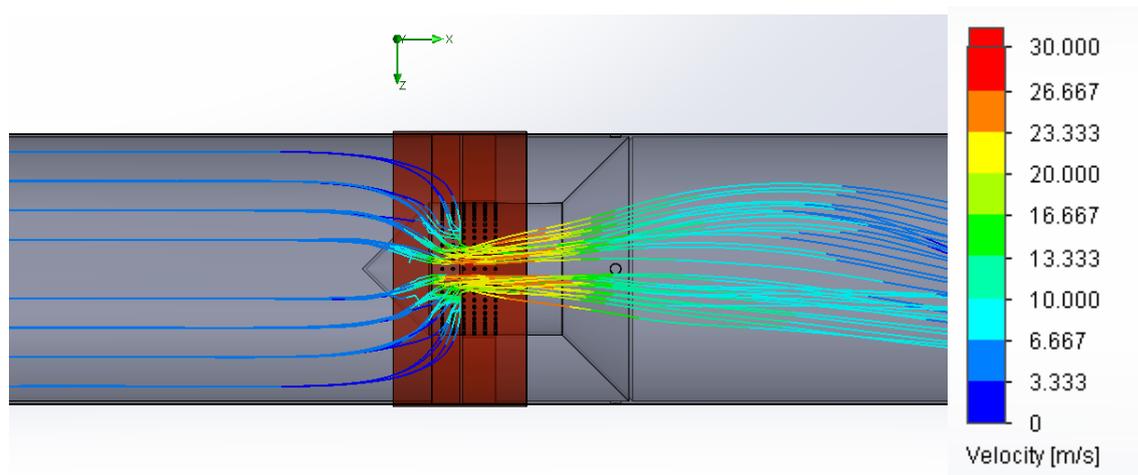


Figure 280: Trajectory plot illustrating the velocity in concept 7

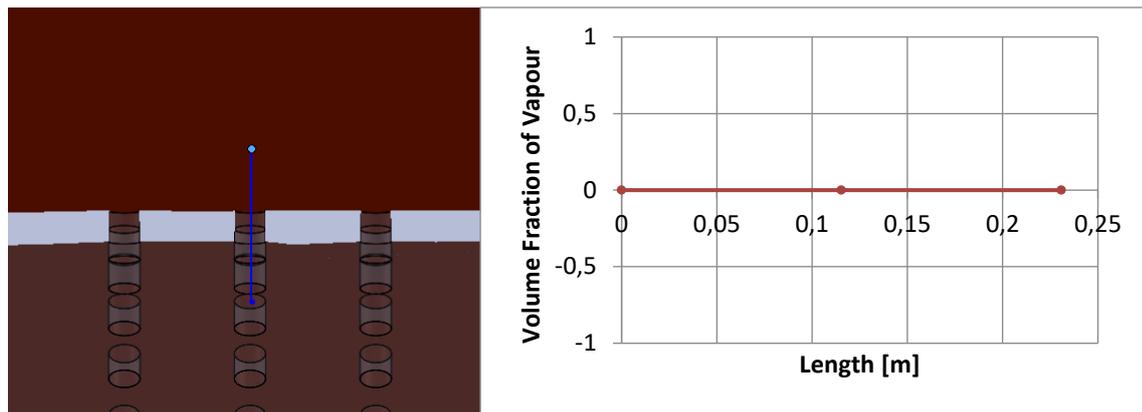


Figure 281: graph illustrating the volume fraction of vapor through vena contracta in concept 7

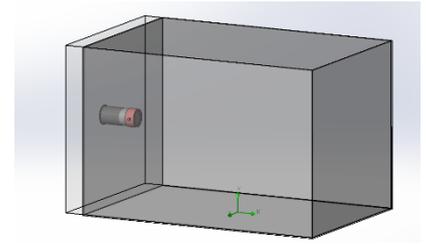
3.7.3 Evaluation

The results from the simulation showed acceptable values. By looking at the graph above, the group can see a volume fraction of vapor at complete zero through vena contracta. The results from the graph can be debatable but can, anyway, be used to conclude that there is a negligible amount of cavitation occurring in this area. The plot for fraction of vapor gives us an understanding where the cavitation is occurring. The vapor can be located in the center of the pipe. This is a location where the cavitation will most likely not damage the construction. Overall, the simulation shows a concept with acceptable values and high potential.

Criteria	Score
Location of cavitation	6
Degree of cavitation	6
Total score	6

3.8 Concept 8: Rock Block

At this point, there isn't any good way to simulate flow through a pile of rocks. The focus will, therefore, be on the flow through the valve. To imitate water flowing into the atmosphere, a large box where the wall on the opposite side of the valve act as the outlet. This is where the water will hit the blocks.



3.8.1 Goal Values

Table 124: Goal Values for concept 8

Goal Name	Unit	Value
GG Max Volume Fraction of Vapor 1	[]	0,055594256
GG Av Velocity 1	[m/s]	0,623264735
SG Volume Flow Rate 1	[m ³ /s]	-7,605642199
SG Av Velocity 1	[m/s]	0,787729621

3.8.2 Results

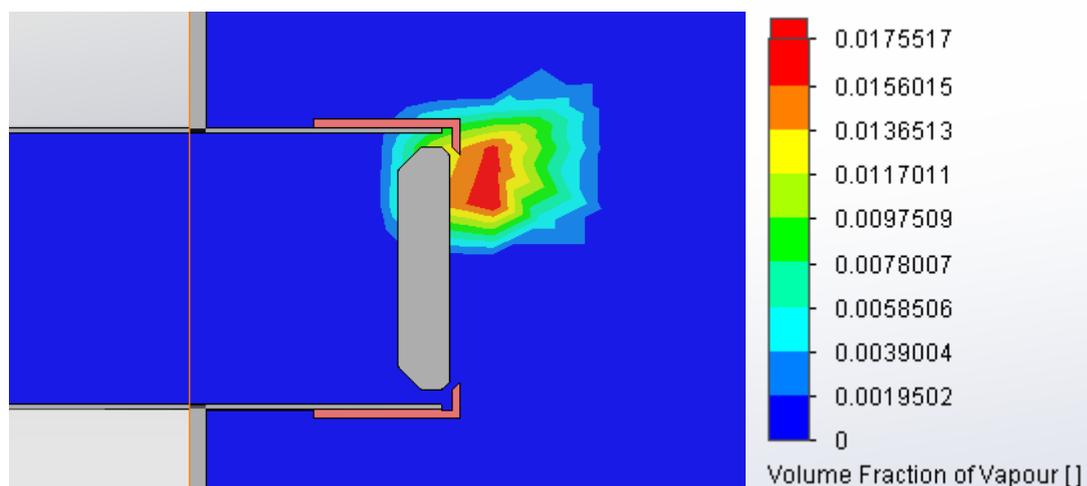


Figure 282: Plot of a cross-section illustrating the volume fraction of vapor in concept 8

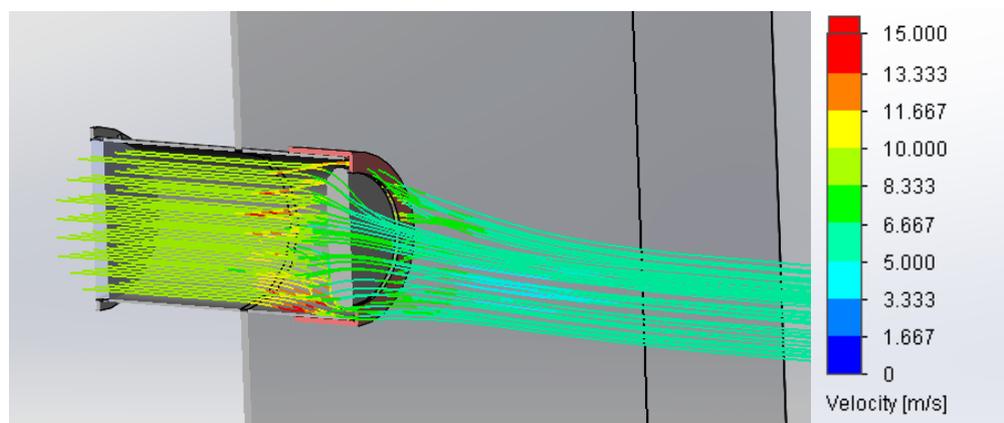


Figure 283: Trajectory plot illustrating the velocity in concept 8

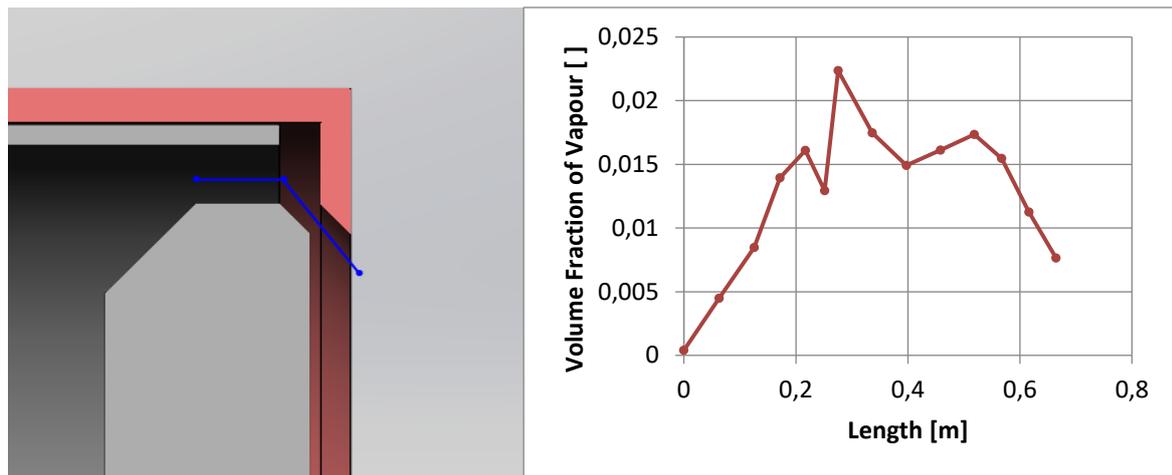


Figure 284: graph illustrating the volume fraction of vapor through vena contracta in concept 8

3.8.3 Evaluation

When evaluating the concept, the group will just look at the flow through the valve. Looking at the plot of the volume fraction of vapor, it is clear that the formation of vapor is right after the valve opening. This area is concerning close to the valve and there will most likely be cavitation occurring here. The graph also emphasizes this argument by presenting a formation of vapor through vena contracta as well. The flow trajectory also gives some inconclusive results, where it presents a higher velocity before than right after the valve.

Criteria	Score
Location of cavitation	3
Degree of cavitation	1
Total score	2

3.9 Concept 9: Rotary cylinder

3.9.1 Goal values

Table 125: Goal Values for concept 9

Goal Name	Unit	Value
GG Max Volume Fraction of Vapor 1	[]	0,969957215
GG Av Velocity 1	[m/s]	4,753585868
SG Volume Flow Rate 1	[m ³ /s]	-
		3,420822215
SG Av Velocity 1	[m/s]	5,247916921

3.9.2 Results

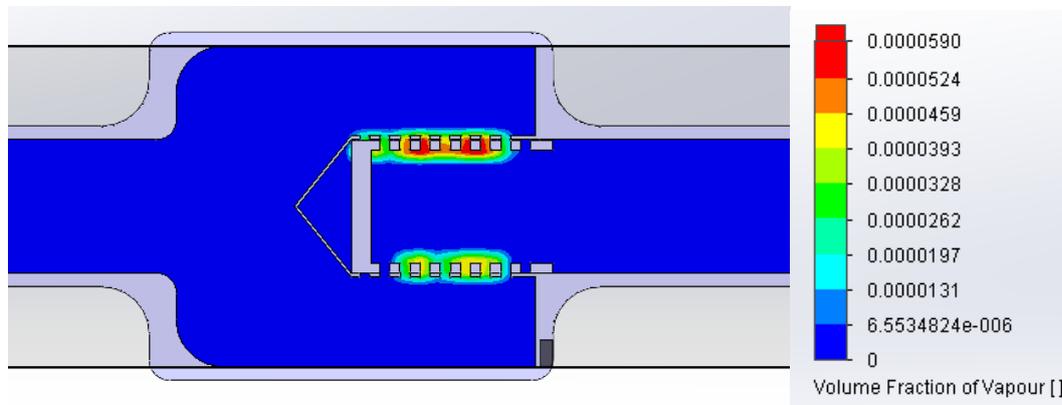


Figure 285: Plot of a cross-section illustrating the volume fraction of vapor in concept 9

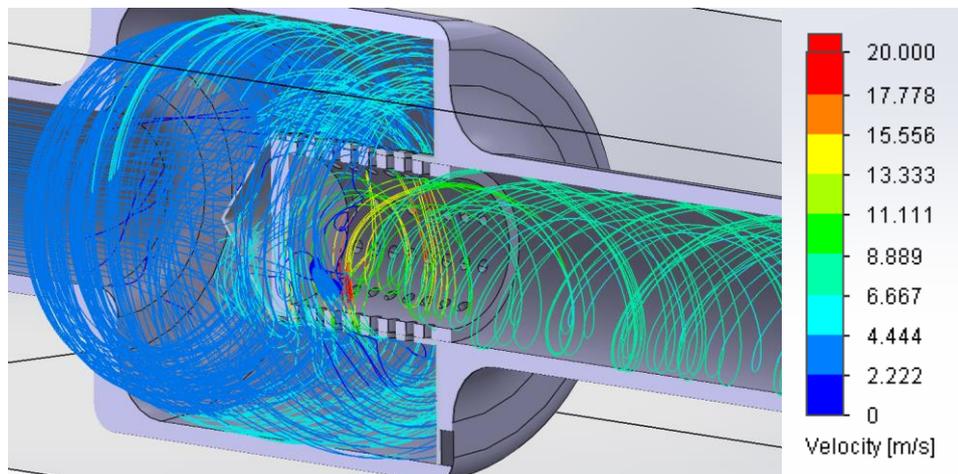


Figure 286: Trajectory plot illustrating the velocity in concept 9

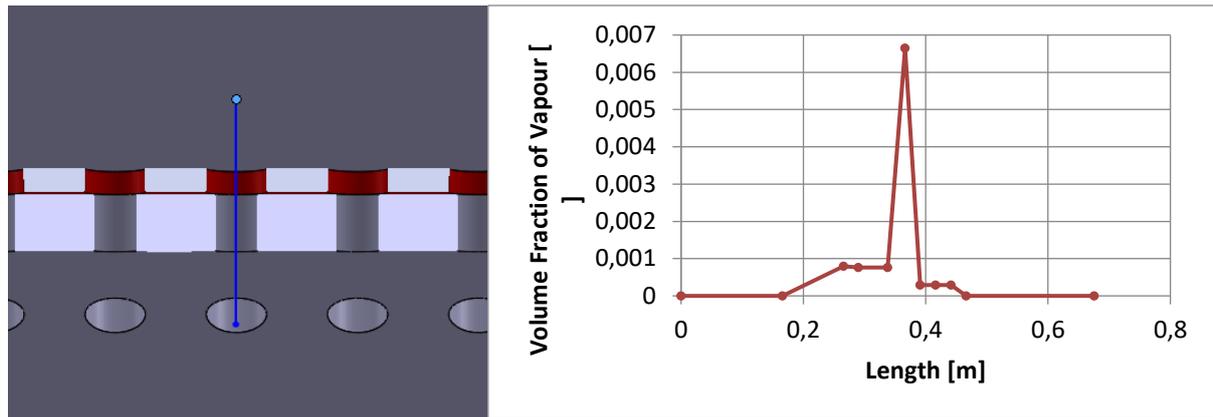


Figure 287: graph illustrating the volume fraction of vapor through vena contracta in concept 9

3.9.3 Evaluation

The flow analysis yields outstanding results in terms of the flow trajectory. The concept creates turbulent flow in the enlarged areas, and the outlet section also has a turbulent flow, which will result in energy dissipation. When looking at the volume fraction of vapor plot and graph, the group can locate the cavitation to be happening in the narrowed section. This is not a desired location and needs to be considered.

Criteria	Score
Location of cavitation	1
Degree of cavitation	1
Total score	1

3.10 Concept 10: Maze

3.10.1 Goal Values

Table 126: Goal Values for concept

Goal Name	Unit	Value
GG Max Volume Fraction of Vapor 1	[]	0,136744434
GG Av Velocity 1	[m/s]	5,613671327
SG Volume Flow Rate 1	[m ³ /s]	2,716357846
SG Av Velocity 1	[m/s]	3,537667878

3.10.2 Results

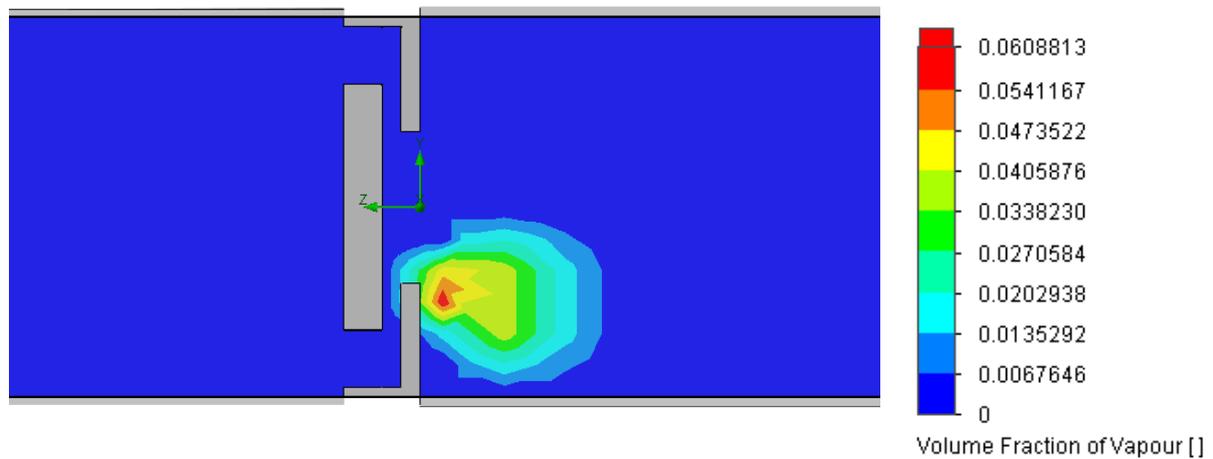


Figure 288: Plot of a cross-section illustrating the volume fraction of vapor in concept 10

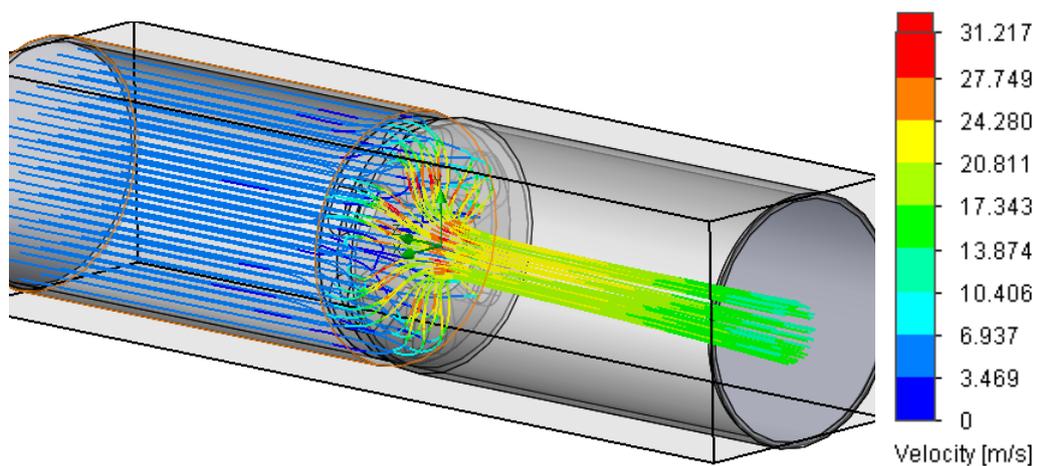


Figure 289: Trajectory plot illustrating the velocity in concept 10

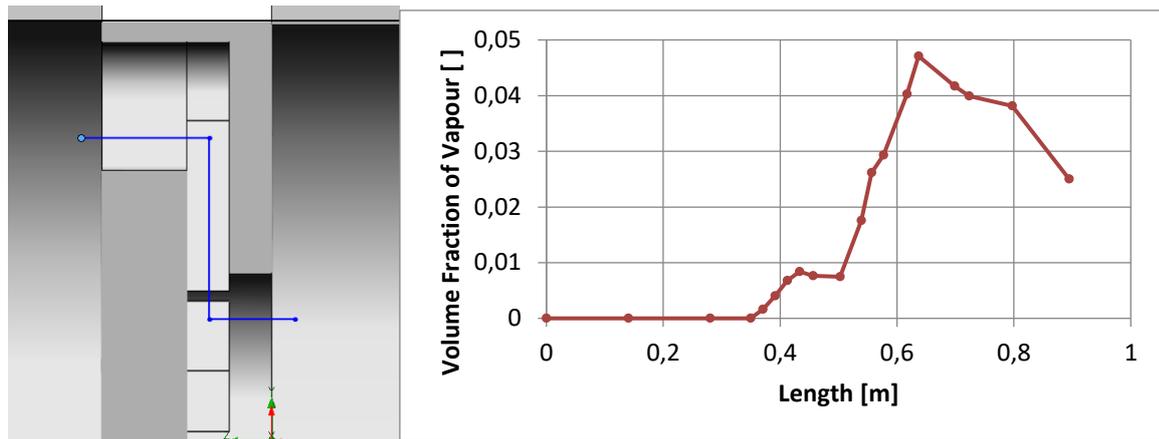


Figure 290: graph illustrating the volume fraction of vapor through vena contracta in concept 10

3.10.3 Evaluation

The volume fraction of vapor is most substantial right after the valve end, where the drop in pressure is the largest. It has a bit low volume flow rate when it is fully open, but this can undoubtedly be modified. The valve does not close yet, which also must be modified to make it viable. In conclusion, this design shows potential but need optimization to fulfill the requirements.

Criteria	Score
Location of cavitation	4
Degree of cavitation	4
Total score	4

4 Gathering of scores

Concept number	Total score
1	6
2	2
3	3
4	5,5
5	3
6	1
7	6
8	2
9	1
10	4

Table 127: Total score



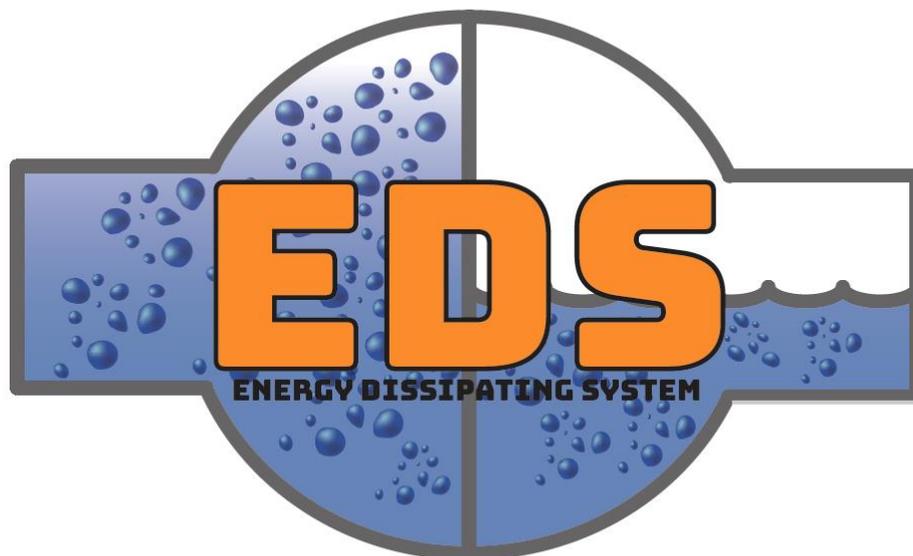
Multiconsult

Design of bypass valve

Appendix L: CFD –

Computational Fluid Dynamics

22.05.2018



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Abstract

Background: The group has used ANSYS Fluent as Computational Fluid Dynamics software to analyze the concept to design.

Method: First, the background of the CFD analysis is briefly explained, to give a better perception of the process developed and a better understanding of the elections made during the setup. Then, the setup of the software and is explained. Finally, the general monitoring and calculation development is shown.

Results: The different options of the configuration of the software are discussed and decided in relation with this project.



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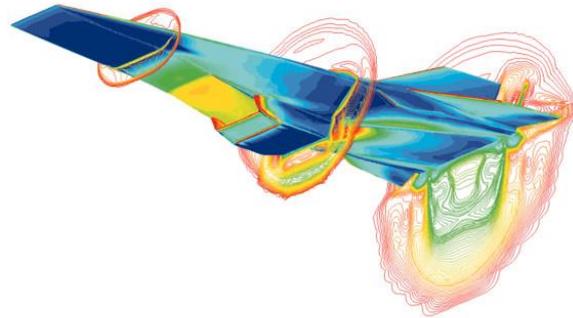
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1 Introduction to Computational Fluid Dynamics

The Computational Fluid Dynamics (CFD) is the area of Fluid Mechanics which leads with the numerical simulation of every kind of fluid behavior, from weather and climate predictions to the combustion process inside an engine (Ferziger & Perić, 2002, pp. V - VII). This great applicability has made CFD software a great tool for engineers, and so, it exists a wide range of software available for this purpose.

The CFD software uses several physical models for solving these different applications. Therefore, the engineer must know the behavior of these models and the software to acquire good results in the simulation.



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 HYPER-X AT MACH 7: This computational fluid dynamic (CFD) image is of the Hyper-X vehicle at the Mach 7 test condition with the engine operating.

Figure 291. Computational Fluid Dynamics (CFD) Image of Hyper-X Research Vehicle at Mach 7 with Engine Operating (NASA, 1997)

1.1 Challenges in CFD

The main challenge in CFD, which doesn't appear in other kinds of numerical analysis, such as the linear static FEM, is its defining equations (Ferziger & Perić, 2002). Specifically, the equations which define the momentum of a fluid: the Navier-Stokes equations. The equation which defines the momentum is a nonlinear equation, meaning it is unstable when solving. This results in a necessity of well-prepared CFD simulation, as a misused CFD tool could end in a non-physical or unrealistic solution.

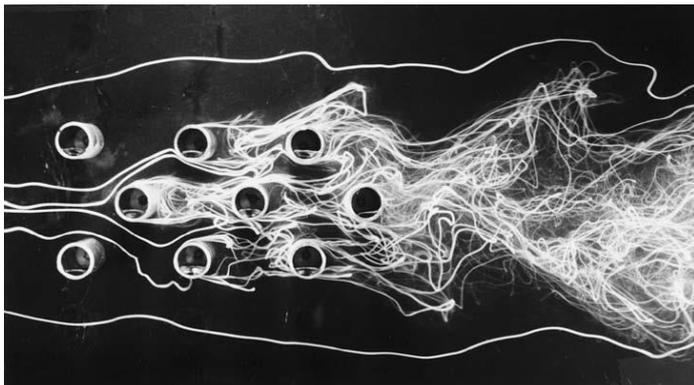


Figure 292. experimental streamlines for actual staggered-array flow at $Re_D \approx 6400$ (White, 2009, p. 554)

Another challenge, not only in CFD but in the subject of Fluid Mechanics in general, is the turbulence. The turbulence is a phenomenon which appears in different grades in almost any industrial fluid application. It doesn't exist any physical law or model which solves turbulence properly and accurately, as it is one of the main historical challenges in Physics.

The last challenge is the same as any computational science: time. Depending on the complexity of the flow to solve and the models used, CFD software needs to solve a different number of equations using an iterative process. This makes some problems unaffordable for normal computers or too time consuming that it isn't worth running the simulation.

1.2 Tasks of the CFD engineer

First of all, a CFD engineer must have a solid background in fluid mechanics and numerical methods (Versteeg & Malalasekera, 2007, pp. 4-6). Only with this knowledge the engineer will be able to set up a good simulation and acquire and judge the results.

The experience with CFD software is also essential. The election of the equations the software must solve is not as evident as it seems. Sometimes, a physical problem involves many equations for describing the behavior of the system. The CFD engineer must be able to decide what are neglectable and what assumptions must be taken to ensure a good representation. Moreover, some models and equation are empirical or semi-empirical. Therefore, the knowledge and experience with these models in combination with real experiments is a great advantage.

Before the simulation, the domain should be discretized in a mesh, so the computer can compute it. This result in a number of points where the calculation is going to be performed. The number of points elected has several consequences: the more points the higher the resolution and the accuracy of the solution, but the higher the time used for the calculation. So, the relationship between time and accuracy should be balanced. This will be explained further in a later sub-chapter.

Another task is the validation of the results. A CFD result can never be completely trusted without an empirical proof. Sometimes, experiments are carried out before the setup of the simulation platform to have reference values. Experiments and tests will always be done after the simulation, in order to validate the simulations.

In conclusion, a CFD engineer should acquire the right balance between accuracy and time, without losing contact with the real behavior.

1.3 CFD in this project

The software used has been ANSYS Workbench 19.0, in the module Fluent, one of the leading CFD Software in the world. The group has access to an academic student license, with the number of cells limited to 512000, not enough for some of the simulations.

Although most of the simulations have ran successfully, the absence of validation in an experiment makes it incomplete.

2 Objective

The main goal of the flow analysis is the optimization of the chosen concept. The result of this optimization should be a design which fulfils the requirements related with the fluid flow.

Requirements linked:

2.1 RQ-1

“The system MUST operate under the pressure of 100- to 300-meter water column.”

2.2 RQ-2

“The system MUST operate with a flow rate up to $3 \text{ m}^3/\text{s}$ ”

2.3 RQ-3

“The system MUST have a predictable flow characteristic”

2.4 RQ-4

“The system MUST manage cavitation satisfactorily”

2.5 RQ-5

“Maximum velocity in the pipeline MUST not exceed 10 m/s”

3 Geometry

There are two different geometries used in the different simulations. The first is a representation of one hole of the valve alone, for optimizing the shape of the holes separated from the rest of the model. And the second geometry is the complete model of the valve.

It should be noticed that the models represent the fluid domain. The CAD models made for the flow analysis represent the fluid part, which is not common. The solid parts of the valve are not represented here.

For example, in the Figure 3 we can see the solid model of the valve. When it comes to prepare it for the flow analysis in Fluent, all the walls and the solid parts are removed and the inner part with water is represented.

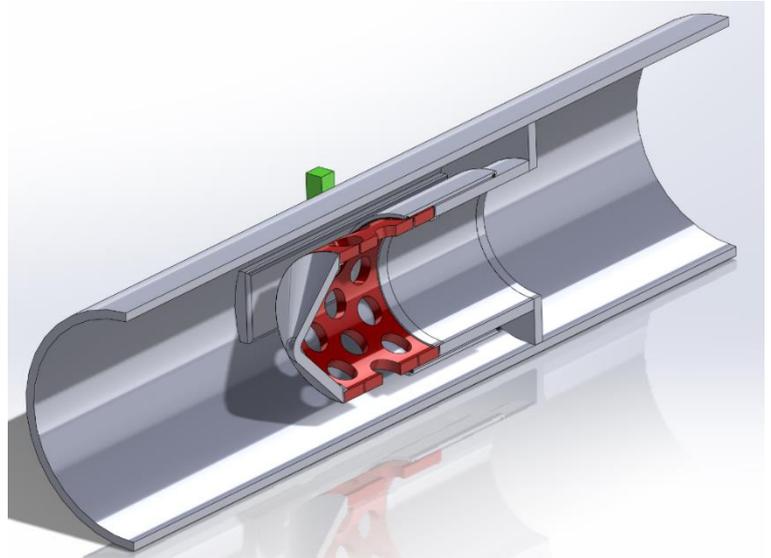


Figure 293. Moveable Pipe 3 CAD model

3.1 Holes

For designing a valve that can withstand cavitation, the group has decided to optimize the shape of the holes separated from the rest of the model (*for a deeper explanation of this decision see Technical document: Flow optimization*). The model is a representation of a single hole, where the water has to go through, with a difference in pressure of 30 bar.

For simplifying the simulation, the geometrical model of the hole is two dimensional and has been calculated as an axisymmetric problem.

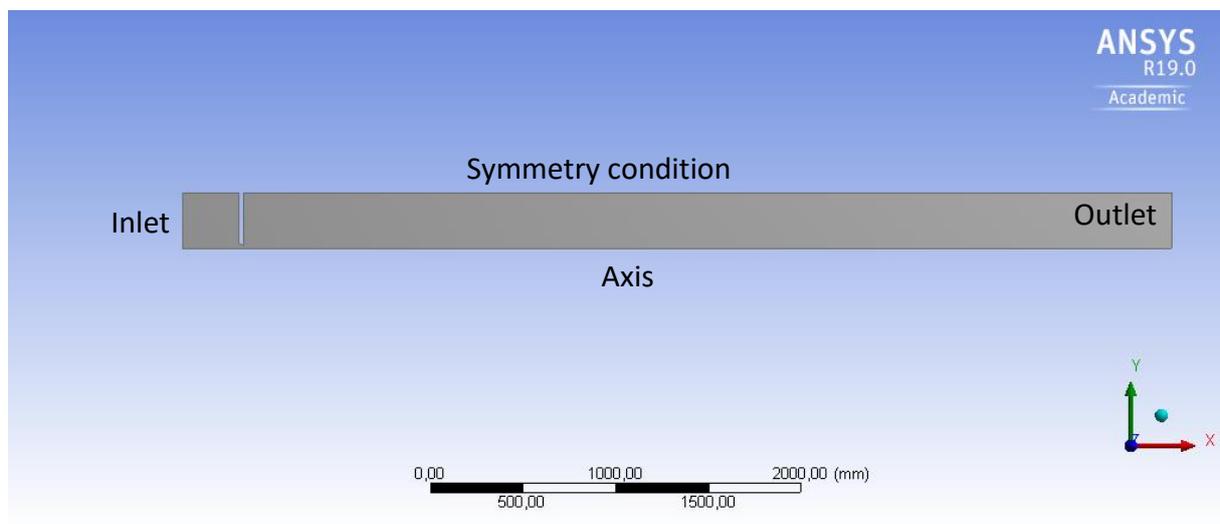


Figure 294. Geometrical model of the simulation of a simple hole

The geometry consists in an inlet on the left, where the fluid enters, and outlet on the right where the fluid exits the problem domain. The top is limited by a symmetry condition, which will be explained in the boundary conditions, and the axis in the top that represent the axis of the axisymmetric geometry. Translated into a 3D model, it would be like the Figure 5.

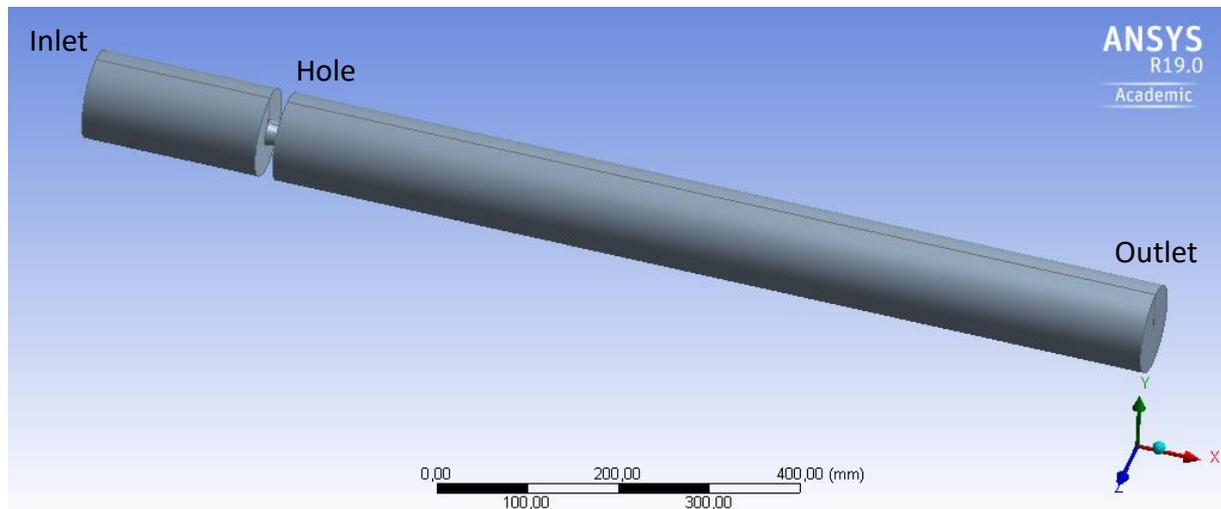


Figure 295. CAD model of the hole in 3D

The detail of the Figure 6 represent the hole and the wall, which is the region of interest in this simulation. The empty zone inside the grey domain represents the solid wall. And the small grey part between the wall and the axis is the hole the water has to go through.

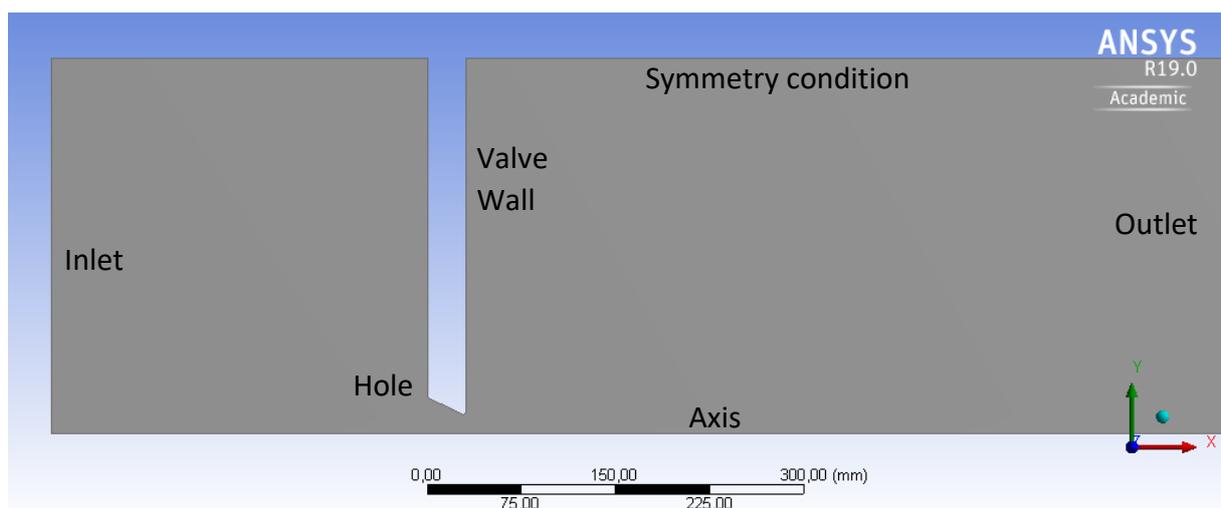


Figure 296. Detail of the geometrical model of the simulation of a simple hole

3.2 Complete model

The geometry comes from the concept phase, where the Moveable Pipe 3 were chosen as the final concept. The model has been designed in the CAD module of ANSYS, as it is easier for the program to work with it. The geometry which has been modeled is the fluid part.

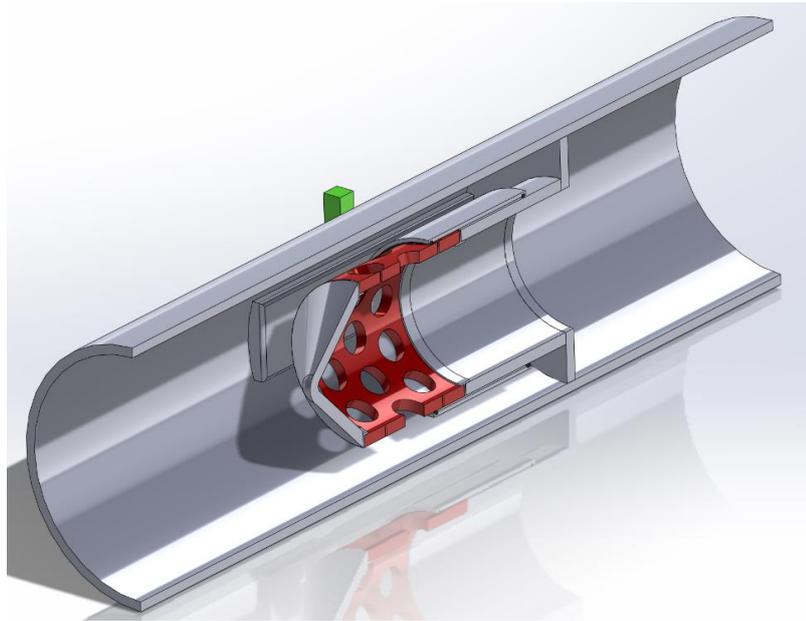


Figure 297. Moveable Pipe 3 CAD model

As the problem is axisymmetric, the results will be the same in every circular sector. This means that the only part which needs to be modeled is one of these circular sectors. And these results can be expanded to the rest of sectors.

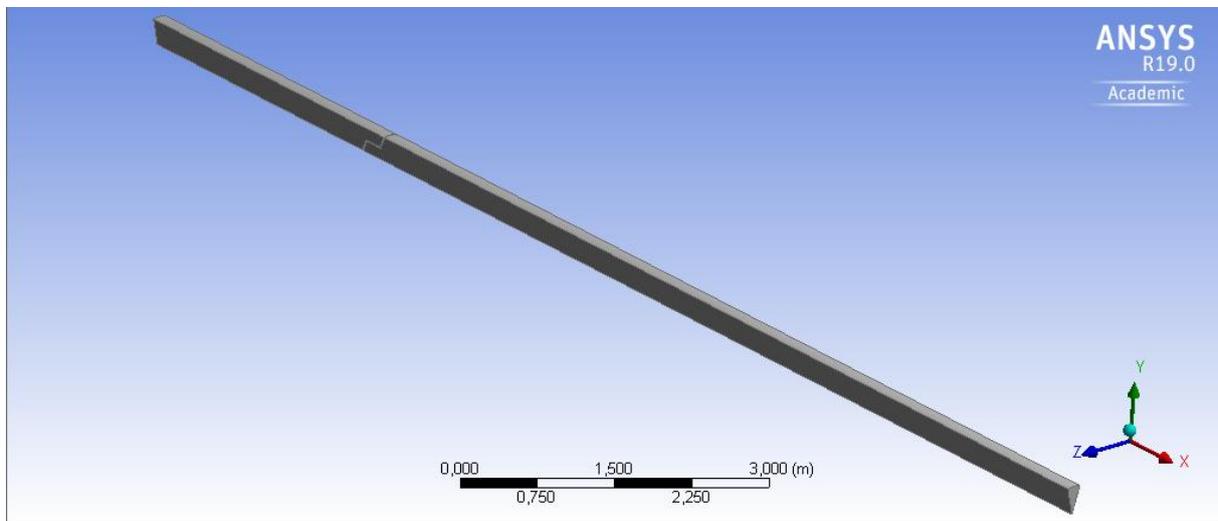


Figure 298. CAD model of the fluid part of the pipe circular sector in the ANSYS Design Modeler Module

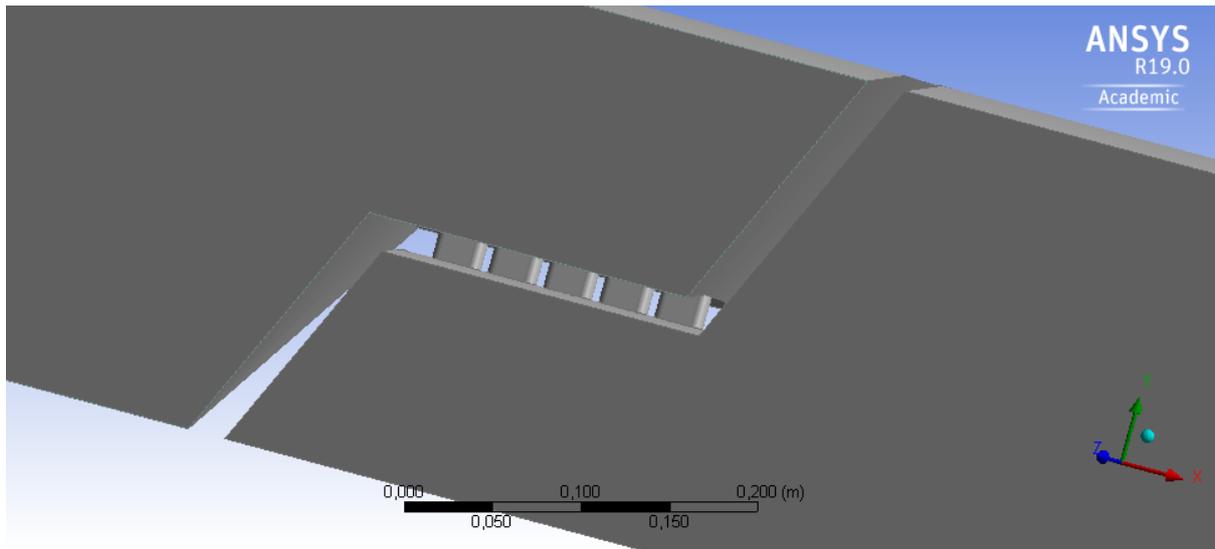


Figure 299. Detail of the valve in the CAD model of the fluid part of the pipe circular sector in the ANSYS Design Modeler Module

In Figure 9, we can see a detailed CAD model of the valve. The gap in the pipeline correspond to the solid part of the valve. The cylinders which cross this gap are the holes of the valve. The fluid is contained inside the grey part, and the limits are the different boundary conditions.

4 Optimization approach

The goal of the flow analysis is the optimization of the shape and configuration of the valve. To acquire the desired results, the optimization should be planned before the setup of the simulation platform.

The optimization process is parameter driven, which means that in the simulation platform some of the parameters has been defined (Table 1), such as the diameter of the holes or the number of rows. Several simulations have been performed varying these parameters. Finally, the group acquires how these parameters are related and what is their influence on the flow characteristics.

Input parameters	Output parameters
Radius of the holes	Flow rate
Number of holes per row	Volume fraction of vapor in solid surfaces
Conic angle of the holes	Mass transfer rate in solid surfaces
Number of rows	Material needed
Thickness of the valve	
Radius of the inner part of the valve	
Length of the inner part of the valve	
Opening grade	

Table 128. Input and output parameters of all the simulations

It should be noticed that all these parameters do not belong in the same simulation. Due to the development of the simulation process, these input and output parameters has been split into several simulations (*see Technical document: Flow optimization*).

After setting the parameters, an objective should be established for the optimization process. This objective must be defined in terms of the output parameters and linked to the requirements. The RQ-1 is given as an input of the simulation as it is the pressure in the inlet of the system. The RQ-2 and RQ-3 are defined by the flow rate parameter, and its relationship with the input parameters. The RQ-4 is directly related with the volume fraction of vapor and mass transfer rate parameters. And the RQ-5 is easily verified measuring the maximum velocity in section of the pipe. However, the group has made a simple calculation to approximate the solution.

$$V = \frac{Q}{A} = \frac{4 * Q}{\pi * D^2} = \frac{4 * 3 \text{ m}^3/\text{s}}{\pi * (0,7 \text{ m})^2} = 7,8 \text{ m/s} \quad (1)$$

$$Re = \frac{D * V * \rho}{\mu} = \frac{0,7 \text{ m} * 7,8 \text{ m/s} * 998 \text{ kg/m}^3}{0,001 \text{ Pa} * \text{s}} = 5,45 * 10^6 \quad (2)$$

Re	4000	10 ⁴	10 ⁵	10 ⁶	10 ⁷	10 ⁸
V/u_{max}	0,794	0,814	0,852	0,877	0,895	0,909

Table 129. Relation of the average speed with the maximum speed in a cylindrical pipe with turbulent flow (White, 2009, p. 367)

$$\text{For } Re = 3,81 * 10^6 \rightarrow \frac{V}{u_{max}} = 0,894 \rightarrow u_{max} = \frac{V}{0,894} = 8,71 \text{ m/s} \quad (3)$$

The objective of the optimization is finding the dimensions which gives a flow rate of 3 m^3/s when it is fully open and the cavitation is managed satisfactorily.

5 Numerical Methods

The computer cannot work with continuous domains (Patankar, 1980, pp. 30-31) (Versteeg & Malalasekera, 2007, pp. 134-136) (Tucker, 2016, pp. 148-149) (Zienkiewicz, Taylor, & Nithiarasu, 2014, pp. 1-3) (Ferziger & Perić, 2002, pp. 39-79). Therefore, this domain should be prepared. For adapting a continuous domain, represented by the physical differential equations of Continuum Mechanics, to a discrete domain there are several methods. The applicability and quality of these methods vary in the different areas and problems.

As it was mentioned in the section Challenges in CFD, the equation which defines the motion of fluids has a strong non-linearity. Non-linear equations need more complex and slow methods to be solved. As a result, the discretization schemes make this equation linear by different approximation algorithms. These algorithms have to discretize the continuous variables as well, so the computer can work with it. The most popular are briefly explained here.

5.1 Finite Element Method

Although the FEM is more extended in Structure Mechanics, there is some software which uses it for CFD. As both, fluid and solid media, present the same problem, a Continuum Mechanics problem, the formulation of the equations is the same. The major difference is that a fluid continuum cannot support differential stresses when it is static. As a result, fluids have differential velocity in the same continuum and solids do not. Therefore, there is a necessity of a more accurate definition of the conservation of the mass, as it is changing its position. Due to its formulation, the FEM needs to be carefully applied to ensure mass conservation. This is the main reason why this method is not very popular in CFD.

Another reason is that a CFD analysis needs more cells than a Structure Mechanics analysis. This is due to the higher gradient of properties because of the differential speed. This results in a bigger necessity of memory in the computer. The FEM needs more memory per cell due to its formulation, and this is a limitation in many cases.

5.2 Finite difference methods

This method is applied to several physical problems defined by differential equations, such as thermal, structural or electromagnetic problems (Ferziger & Perić, 2002, pp. 39 - 58). The reason is its ease of implementation and great applicability.

The method consists of dividing a given domain in discrete points. As seen in Figure 10, the points are the discrete domain where the solution is calculated, these points form the grid and are called nodes. The white nodes are the interior of the domain and the black ones are the boundaries of the domain.

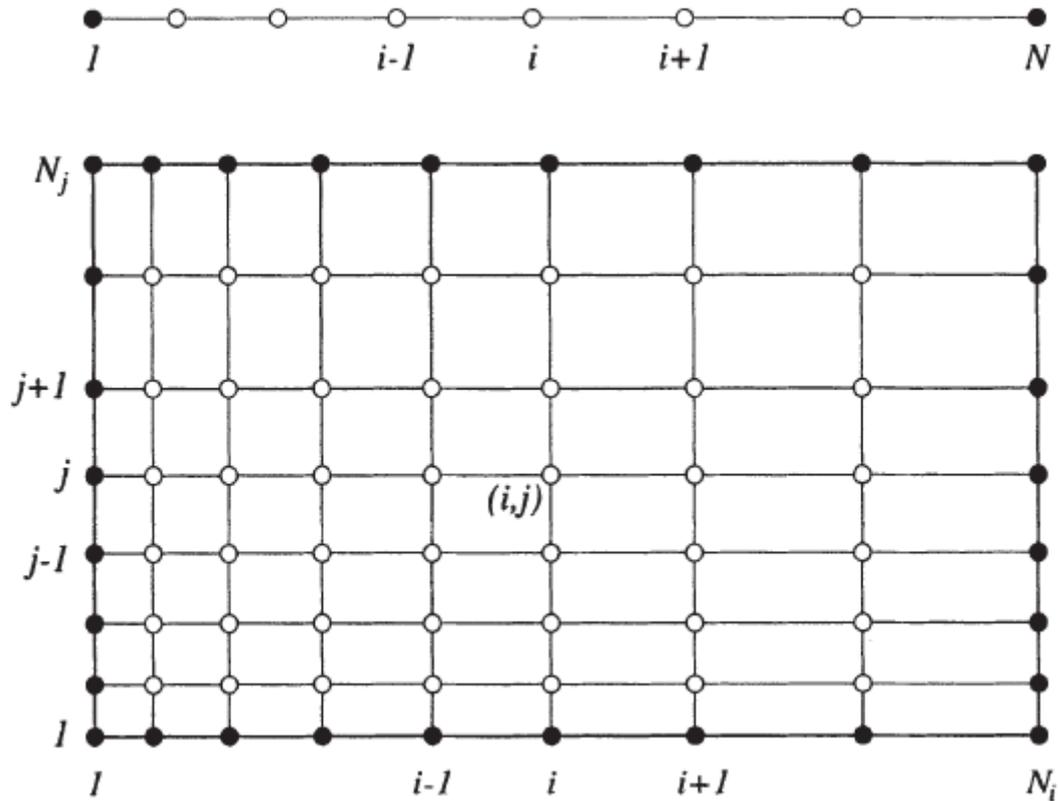


Figure 300. An example of a 1D (above) and 2D (below) Cartesian grid for FD method (full symbols denote boundary nodes and open symbols denote computational nodes (Ferziger & Perić, 2002, p. 40)

The approximation of the derivatives by finite differences comes from the definition of derivative. There are several methods to define it. Here it is the example of the first order derivative by a first order Taylor Series:

$$\left(\frac{\partial \Phi}{\partial x}\right)_{x_i} = \lim_{\Delta x \rightarrow 0} \frac{\Phi(x_i + \Delta x) - \Phi(x_i)}{\Delta x} \approx \frac{\Phi_{i+1} - \Phi_i}{x_{i+1} - x_i} \quad (4)$$

The approximation of a derivative in one node requires taking the value of at least two nodes. These could be taken from a combination of any node close to the objective node. In the Figure 11, different ways for approximating the derivative on a given function is shown.

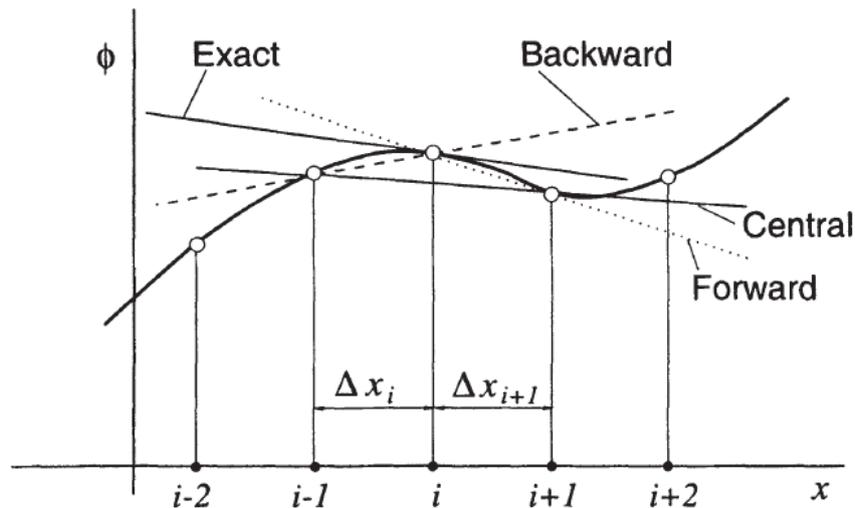


Figure 301. On the definition of a derivative and its approximations (Ferziger & Perić, 2002, p. 41)

By these and other approximations, the derivatives of the differential equations are transformed into simple differences. The continuous variables are transformed into discrete variables in the nodes. These discrete variables are now related by algebraic equations, which are linear or have been linearized, and can be fitted in to an algebraic equation system.

This is the discretization transformation for the Equation of Diffusion for fluid domains. This equation defines the distribution of scalar variables in the fluid domain when the fluid motion is known.

$$\frac{\partial(\rho u \Phi)}{\partial x} = \frac{\partial}{\partial x} \left(\Gamma \frac{\partial \Phi}{\partial x} \right) \rightarrow \rho u \frac{\Phi_{i+1} - \Phi_{i-1}}{x_{i+1} - x_{i-1}} = \frac{\left(\Gamma \frac{\Phi_{i+1} - \Phi_i}{x_{i+1} - x_i} \right)_{i+1/2} - \left(\Gamma \frac{\Phi_i - \Phi_{i-1}}{x_i - x_{i-1}} \right)_{i-1/2}}{\frac{1}{2}(x_{i+1} - x_{i-1})} \quad (5)$$

Finally, we have a system of linear algebraic equations which relates the different values of the different nodes. Therefore, the problem is solved by a linear algebraic solver.

5.3 The Finite Volume Method

This is the most extended method in CFD. The FDM presented above present good results in diffusion problems, problems where the velocity field is already defined. However, when the problem include convection, which means that the velocity field must be calculated, the solution is more complicated.

The FVM consist in dividing the domain into several discrete points, called nodes, as the FDM does. However, the FVM divides the continuous domain as well in several nonoverlapping control volumes, called cells. Each of them surrounds each of the discrete points defined

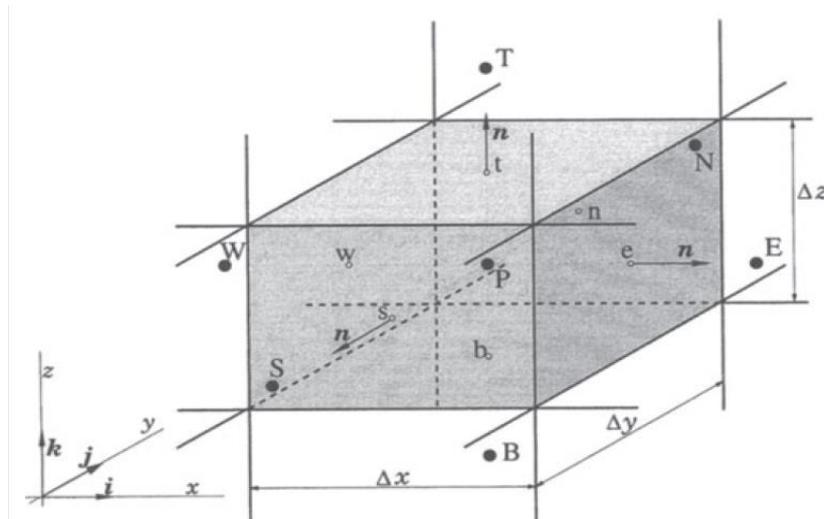


Figure 302. Typical hexahedral cell with the notation used for defining its different parts (Ferziger & Perić, 2002, p. 73)

before. By defining these volumes around the nodes, the FVM can apply the conservation equation in its integral form. Applying the integral form to each cell ensures a much better conservation of the different variables, instead of to the whole domain, which can result in a non-physical solution.

The FDM uses the differential form of the conservation equations (Equation 5). The FVM uses the integral form of these equations (Equation 6):

$$\int_A \vec{n} \cdot (\rho \Phi \vec{u}) dA = \int_A \vec{n} \cdot (\Gamma \nabla \Phi) dA + \int_{CV} S_\Phi dV \quad (6)$$

This equation expresses the conservation of a general property ϕ in a control volume. The term on the left expresses the variation of the property inside the control volume, the central term means the net flow of the property ϕ through the limits of the control volume, and the term on the right is the generation of this property inside the control volume. \vec{n} is the vector normal to the external surface of the control volume, ρ is the density, Φ is the variable of study, \vec{u} is the velocity vector, Γ is the diffusion coefficient of Φ , A is the area of the external surface of the control volume, dA is the differential of the previous area, S_Φ is the generation per volume unit of Φ , CV is the control volume, dV is the differential of volume and $\int_G f(x) dG$ is the integral of the function $f(x)$ per differential value of the domain G along the domain G .

As an example, the group is going to apply the FVM to a 2D square control volume.

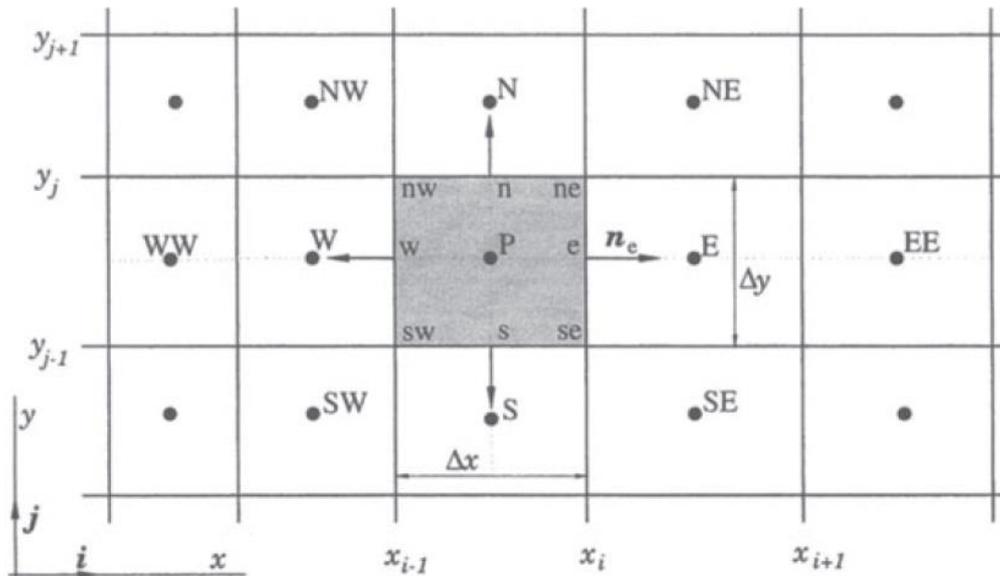


Figure 303. Schematic representation of a cell around the node P, and its neighbor cells (Ferziger & Perić, 2002)

The control volume is referred to the cell of the node P (Figure 13), where its external surface is in contact with its neighbors N, E, W and S. The capital letters are used for calling cells and the small letters are the names of the external surfaces of the control volume.

For discretizing the Equation 6, we have used the central difference scheme as in the previous section, neglecting the source term. For the complete discretization process see (Versteeg & Malalasekera, 2007, pp. 134-136). The different methods of discretization available are explained in the subsection Methods.

$$F_e \Phi_e - F_w \Phi_w = D_e (\Phi_E - \Phi_P) - D_w (\Phi_P - \Phi_W) \quad \text{where } D = \frac{\Gamma}{\delta x}, F = \rho u \quad (7)$$

The subscript of the variables means where the values are calculated.

After the discretization results a linear equation for each cell. The variables of the different cells are related by these equations. Therefore, it results in a linear system of equations.

5.4 Our software

The Finite Difference Method is almost not used, and the Finite Element Method is used only in a few software's. The software used, ANSYS Fluent, uses the Finite Volume Method. This method is the most widely used and the objective of most of the investigation in CFD.

There are more types of software, especially for those problems where these numerical methods are do not work properly.

6 Mesh

A computer can only work with discrete domains, that is why the continuous domains, such as a fluid domain, has to be divided in finite parts. This division is called mesh in computational mechanics. The mesh has to be prepared for the following simulation. The accuracy, computational time and validity of the simulation have a strong relationship with the mesh.

A finer mesh results in a more accurate solution, as the number of points where the solution is obtained is bigger. However, more points mean more equations that must be solved, and so, more computational time required.

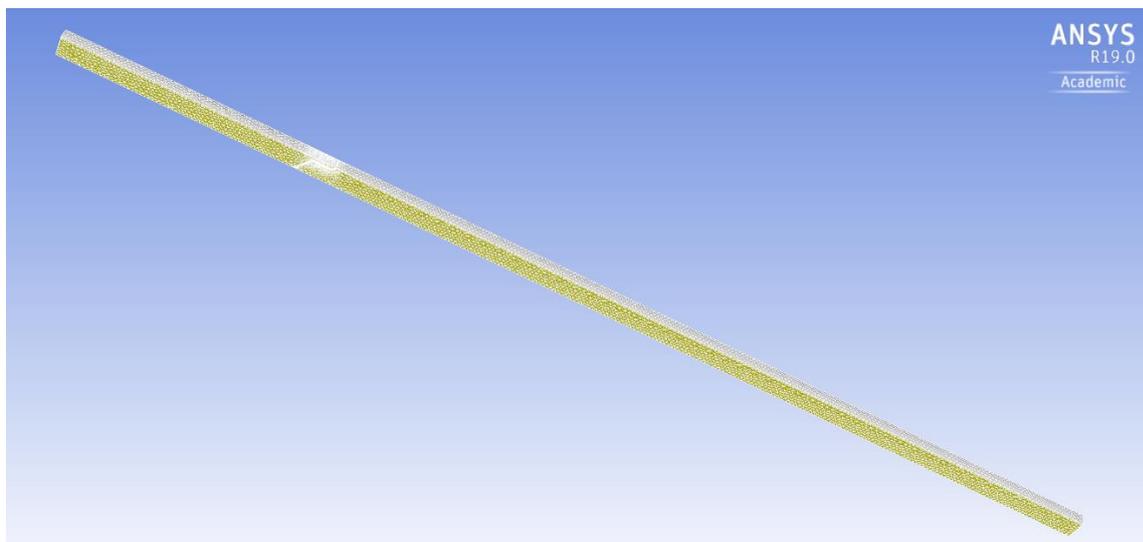


Figure 304. Mesh of the ANSYS Workbench Fluent model

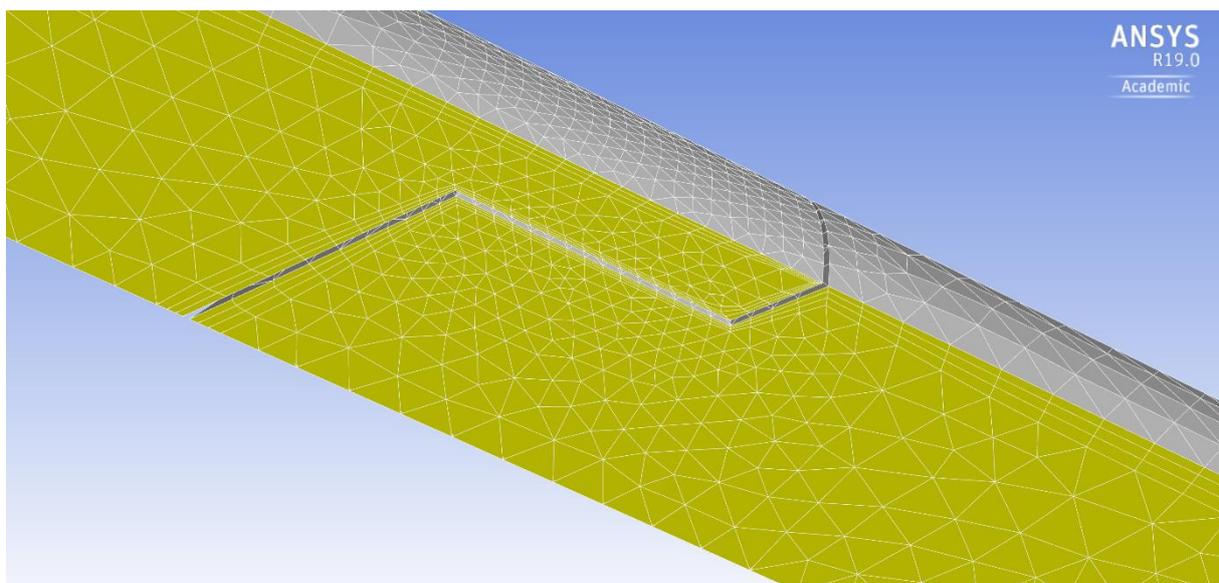


Figure 305. Detail of the mesh in the valve part

6.1 Mesh and CFD

In CFD, the relation of the mesh with the solution process and the results is strong. The mesh must fulfil two conditions: quality and size. These quality and size are defined by the shape and size of the cells. The cells are the divisions of the domain which result from the mesh discretization.

6.1.1 Mesh quality

The mesh quality is related with the method used for the discretization of the equations (Fluent Inc., 2006, pp. 199-200). This method is the Finite Volume Method in most of the CFD software, and in ours. The literature says that the best mesh is made of regular and structured hexahedrons, or squares in 2D meshes (Ferziger & Perić, 2002, pp. 26 - 27). However, the mesh must be adapted to the geometry. That is why a mesh made of hexahedron is barely difficult to implement in complex geometries. We can see an example in Figure 16. Therefore, the tetrahedral mesh is more popular for 3D models as it is easier to adapt.

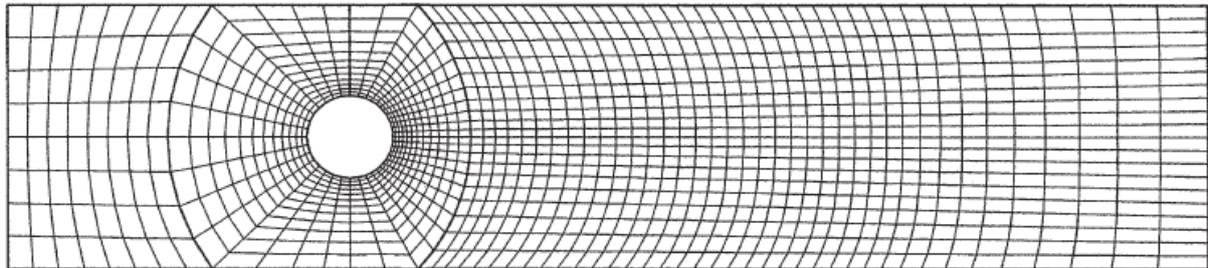


Figure 306. Example of a 2D block-structured grid which matches at interfaces, used to calculate flow around a cylinder in a channel (White, 2009, p. 28)

As a general rule, there are two parameters to track the quality of the mesh: the aspect ratio and the orthogonal quality.

The aspect ratio is the relation between the bigger and the smaller face of a cell. The literature says that this ratio should be smaller than 40 for 3D problems. This must not be considered as an absolute limit, however, it is a useful rule for a preliminary mesh.

The orthogonal quality measures the degree between the faces of a cell. The literature establishes the limit in 45° . Although this depends on the problem, under this value acquiring a good solution may be difficult. The orthogonal quality ranges from 0 to 1, and the CFD software companies set the limit of this value in 0.01.

6.1.2 Mesh preparation

Due to the discrete performance of this process, the variation of the values along the domain it is captured by interpolation of single points. Therefore, a strong variation needs more nodes than a weaker one, or the result will not be real. Considering this, the mesh should be prepared for the expected results. So, the solution must be guessed before running the calculation. It should be finer where the variation of the variables, the gradient, is greater. And there, a finer mesh should be implemented.

6.2 Mesh setup

In order to prepare the mesh for the following calculation, ANSYS Workbench has a Mesh Module. This mesh module allows you to perform meshing operations which define the size and shape of the mesh. These meshing operations are for the mesh preparation explained above this section. Meshing operations used:

- Maximum vertex length of a cell: to ensure a minimal accuracy in the simulation the group has set a maximum size for the cells. This measurement ensures a maximum size of the cell size in the whole domain. This value varied during different calculations.
- Face sizing: This operation allows you to select several faces of the domain and set a maximum size for the cells which are in contact with it. The group has performed this operation in the holes of the valve. A finer mesh was needed inside them because the drop of pressure happens inside them.
- Inflation layer: An inflation layer is a deformation of the mesh. It is performed next a surface which have been selected previously. It consists in changing the size in only one dimension of the cell. The perpendicular direction to the selected surface is changed and the other dimensions remain constant. This is performed to have more cells in the perpendicular direction of the surface. And so, avoiding increasing too much the number of cells. By having more cells in the perpendicular direction of the wall, the group could capture the fast variation of speed form the solid surfaces.

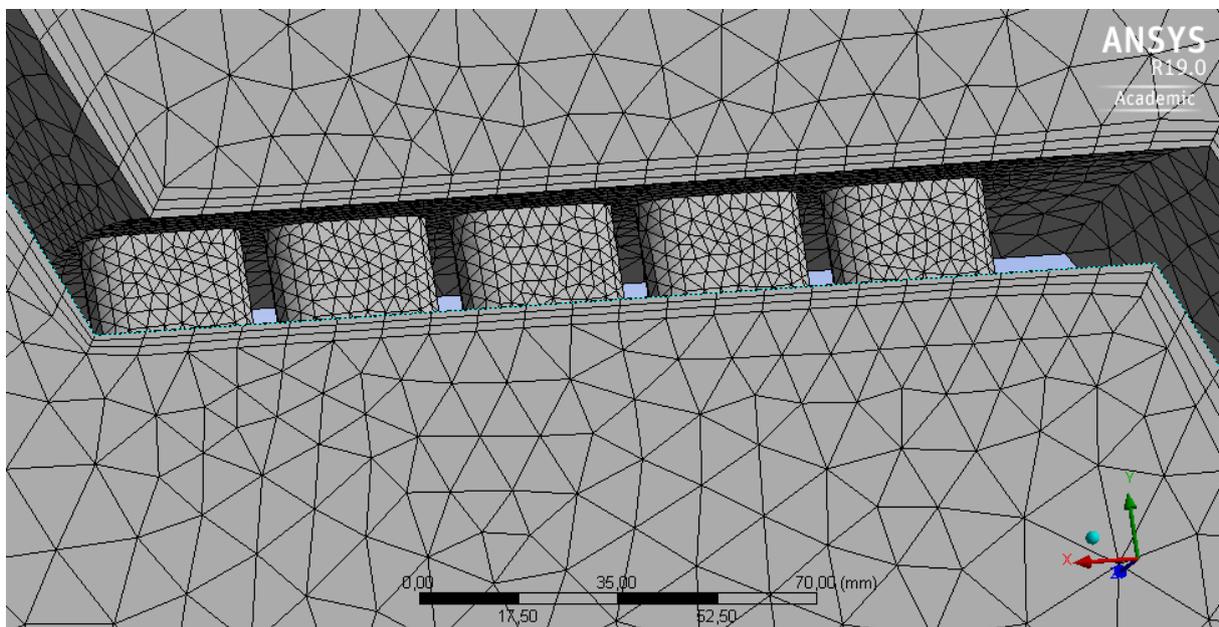


Figure 307. Detail of the mesh in the valve in the Meshing Module of ANSYS Workbench 19.0.

We can see a detail of the mesh in the Figure 17. A Face Sizing operation has been performed in the cells. Furthermore, In the valve walls the cells have been deformed in the perpendicular direction of the surface due to the Inflation Layer operation.

6.3 Resulting mesh

Although the mesh has been changed for different simulation and the geometry has changed several times, the results of the mesh quality are almost constant. The Meshing Module offers a variety of tools to analyze the mesh quality. The group has plotted the Aspect Ratio and the Orthogonal Quality in relation with the number of elements.

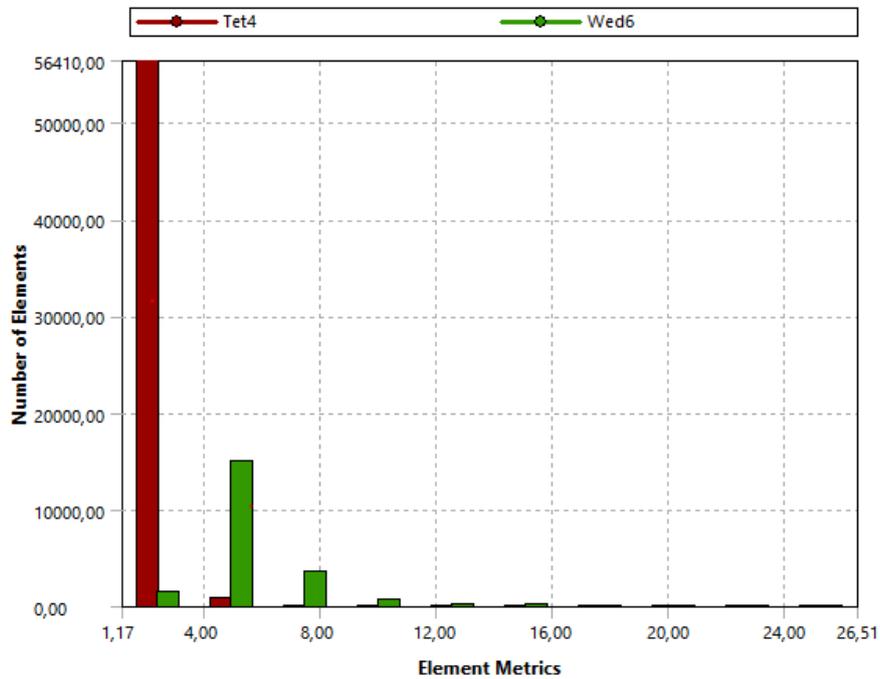


Figure 308. Number of elements within each interval of values of the Aspect Ratio

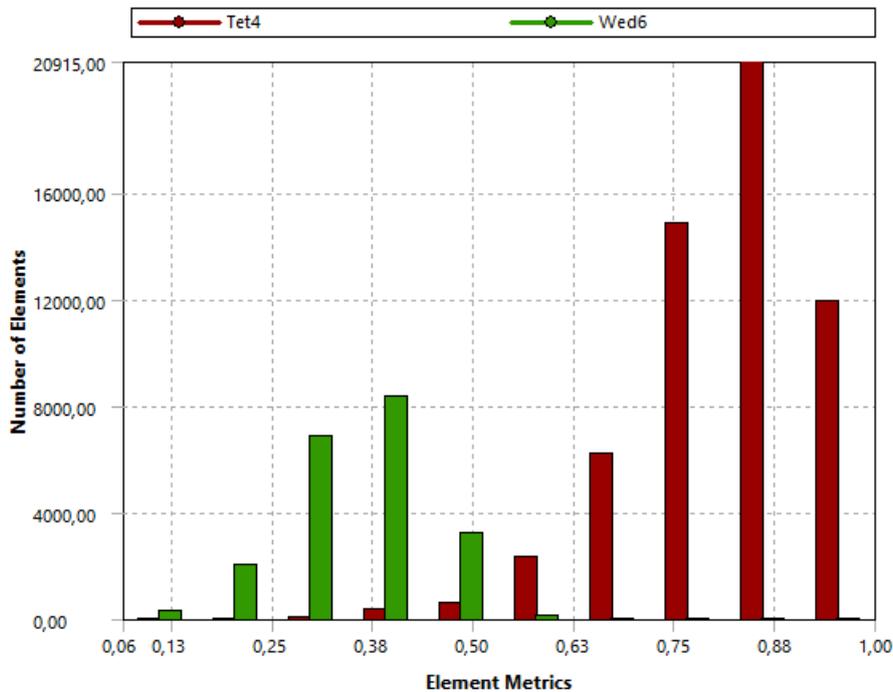


Figure 309. Number of elements within each interval of values of the Orthogonal Quality

As explained in the subsection 6.1.1 Mesh quality, these values should be under certain limit. The aspect ratio should be under 40, which is fulfilled. And the orthogonal quality has 0.01 as limit, which is also fulfilled.

7 Setup

The setup of the simulation is the definition of the problem to solve (Fluent Inc., 2006, p. 2323). In this part, the equation to be solved are defined and the conditions in which the problem is operating. Through the next subsections, the path followed to prepare the simulations is explained.

The setup and the solution process are carried out in Fluent, the flow analysis module of ANSYS.

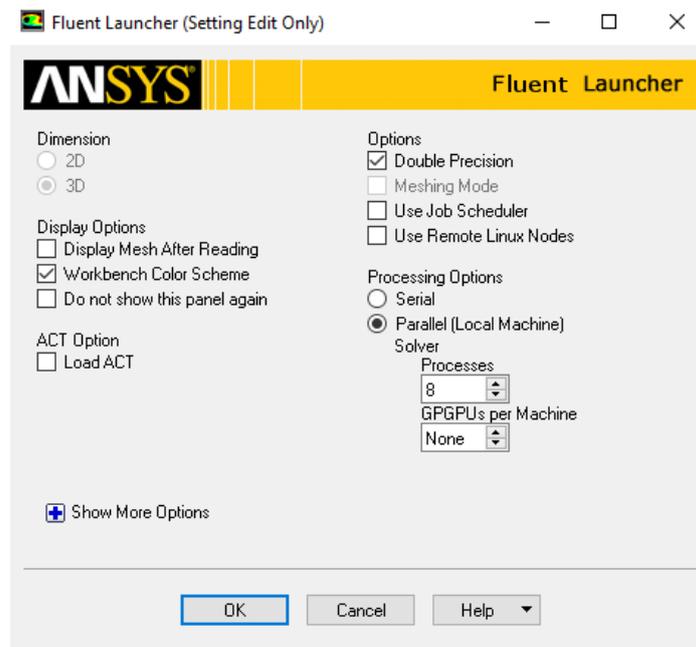


Figure 310. Fluent launcher with the initial setup

For the following calculation, some parameters must be predefined. In the Figure 20, the panel for this predefinition is shown.

For the numerical analysis, the group has used double-precision, which means the number of significant figures of the numbers. The double-precision uses numbers with a 64-bit float format, instead of the single-precision, which uses 32-bit float format. As it doesn't mean too much requirements of memory and ensure that the truncation error during the simulation is minimized, it is the best option for most CFD simulations.

The group has used a computer with 8 i7 processors, and Fluent allows you to divide the computational effort between several processors to optimize time. Therefore, *parallel* option is marked with 8 processors.

7.1 Domain

The domain is given by the geometry model defined previously, as well as the mesh. However, some setting can be modified for the simulation process.

7.1.1 General

When setting up the physical properties of the problem, the type of problem should be defined first by some characteristics (Fluent Inc., 2006):

- Steady-state: the solution doesn't have a dependency of time. The other option is transient solution. This is applied to calculations where the solution varies in time. All our simulations are steady-state.
- Pressure-based solver: this option is for electing the solver, the options are pressure-based and density-based. This refers to the variable which drives the flow: pressure or density. Density based solver is usually applied to compressible fluids at high speed, and that is not our case. The group choose used pressure-based solver.
- Reference of frame: this option doesn't have any relevance in this problem. It is referred to the frame of reference when there are moving walls. In this problem all the walls are stationary.

7.1.2 Models

During the setup of the simulation, the physical equations which must be solved must be specified (Versteeg & Malalasekera, 2007, pp. 9-24). After specifying the different equations, a model must be chosen for each of them. A model represents the numerical algorithm the computer follows to solve the physical equation. Here, the ones used are presented.

7.1.2.1 Flow

This is the default equation. It is applied to any flow and represents the analysis of the speed and pressure of any fluid. This is the fundamental model as it provides the definition of the movement of the fluid. This model solves the continuity and momentum conservation equations. Now, these equations are presented for laminar flow to give an overview.

7.1.2.1.1 Mass conservation equation

The mass conservation equation ensures that the mass along the system is not disappearing or being created. The equation for compressible and incompressible fluids, in the differential form, can be written as follows:

$$\frac{\partial \rho}{\partial t} + \text{div}(\rho \vec{v}) = 0 \quad (8)$$

Where ρ is the density, t is the time, $\frac{\partial \rho}{\partial t}$ is the partial derivative of the density with the time, \vec{v} is the speed vector and div is the divergence operator.

This equation expresses the conservation of the mass in a given volume, differential volume in this case. The term $\frac{\partial \rho}{\partial t}$ means the variation of the mass with the time. The term $\nabla(\rho \vec{v})$ means the variation of the mass in the space. The sum of them is equal to zero.

7.1.2.1.2 Momentum conservation equation

The momentum equations include the pressure and velocity of the fluid. This means that they define the movement of the fluid in the domain. The momentum equation for incompressible laminar flow of a Newtonian fluid in the x-direction, in its differential form, can be written as follows:

$$\frac{\partial}{\partial t}(\rho u) + \text{div}(\rho u \vec{v}) = -\frac{\partial p}{\partial x} + \text{div}(\mu \nabla u) + S_{Mx} \quad (9)$$

Where ρ is the density, t is the time, \vec{v} is the speed vector, u is the velocity in the x-direction, ∇ is the gradient operator, div is the divergence operator, $\frac{\partial}{\partial x}$ is the partial derivative in x , p is the pressure, μ is the dynamic viscosity and S_{Mx} is the source term, which means the generation of x-momentum per volume unit.

The term $\frac{\partial}{\partial t}(\rho u)$ is the variation of x-momentum in time, $\text{div}(\rho u \vec{v})$ is the variation of x-momentum in space, $\frac{\partial p}{\partial x}$ is the variation of pressure the x-direction, $\text{div}(\mu \nabla u)$ are the forces originated due to the viscous stresses and S_{Mx} is the source term.

The nonlinearity mentioned previously in this document which conditions this process comes from this equation. The term $\text{div}(\rho u \vec{v})$ is multiplying the velocity per itself, making the spatial variation of the velocity nonlinear.

7.1.2.2 Turbulence

The equations presented above represent the fluid motion for laminar flow, but the turbulent flow is not well-defined by them, specially at highly turbulent flows (White, 2009, pp. 349-352) (Versteeg & Malalasekera, 2007, pp. 40-49). There are a huge range of methods, algorithms and equations which attempt to define the turbulence. None of them are valid for every application, so the election of the model turbulence is essential for a valid result in CFD.

For explaining the turbulence models, some concepts should be introduced first:

The turbulence can be explained in several different ways. The most common is by a relative ratio of forces. The ones due to the speed and the ones due to the viscous stresses. This ratio is the Reynolds Number, and this certain value depends on the geometry.

$$Re = \frac{vD\rho}{\mu} = \frac{v\rho}{\frac{\mu}{D}} = \frac{\text{inertial forces}}{\text{viscous forces}} \quad (10)$$

When a flow gets turbulent, the average velocity is constant, however, the speed of the fluid in a point has rapid and random changes. These changes do not appear suddenly, they have a transition interval.

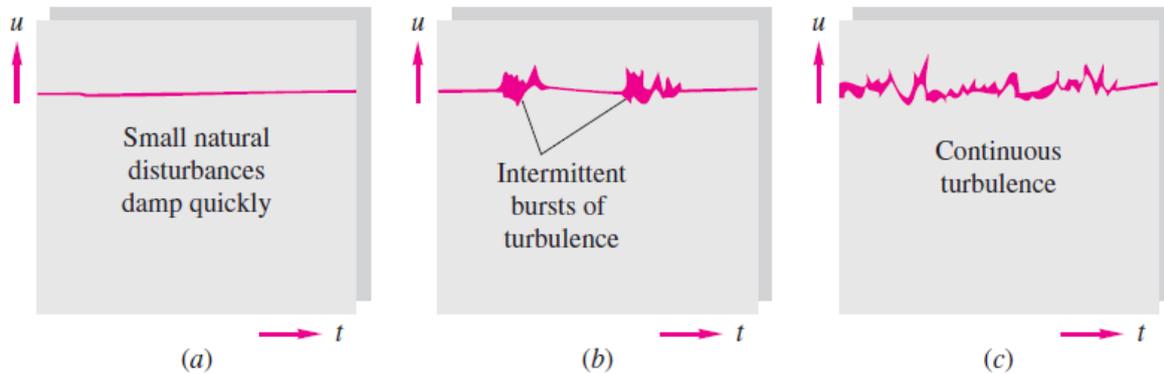


Figure 311. Variation of the speed profile in a point depending on the turbulence degree.

The main challenge of the turbulence models is leading with these random and chaotic changes in speed. Depending on the path taken for this purpose the turbulence models can be divided into three categories:

7.1.2.2.1 Direct Numerical Simulation (DNS)

DNS models are the simple approach of using a very fine mesh in a transient simulation (Versteeg & Malalasekera, 2007, pp. 110-113). By this approach, any variation in the flow and representing every characteristic of the turbulence is captured.

This method requires extremely powerful computational facilities. Therefore, is not valid for industrial application where models may need modifications and several trials. However, these models provide very detailed information about turbulent flows. Other models and experimental analyses use this information for its definition and validation. DNS is mainly limited to the academic world.

7.1.2.2.2 Large Eddy Simulation (LES)

An eddy is defined as “Swirling of a fluid with reverse streamlines created when the fluid flows past an obstacle, a curvature, or a region with diameter change” (Chiu & Chien, 2011).

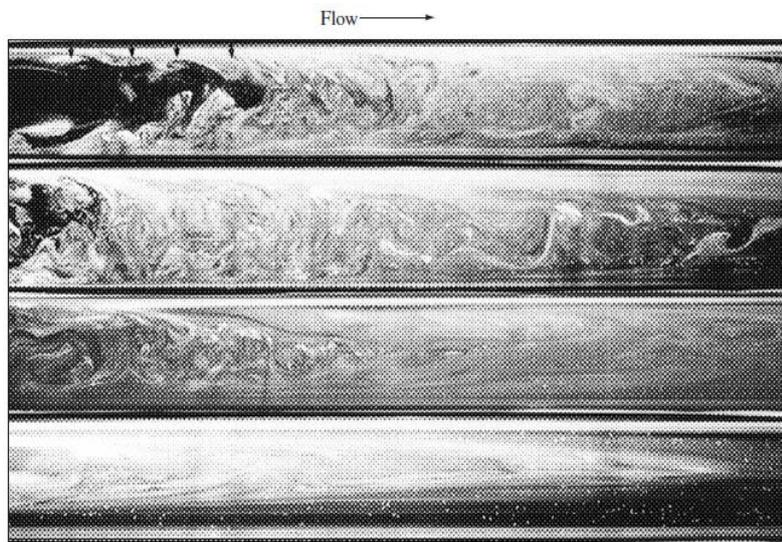


Figure 312. Different sizes of eddies in different positions of the same pipe due to the turbulent characteristic (White, 2009, p. 350)

making the average in time of these variations, but simulates the variation in time of the big ones. This solution provides less detailed results. However, it decreases the computational capacity necessary as it needs much less nodes. The filtering of eddies is produced by coarsening the mesh, so the small variations of speed are not captured when they are smaller than the mesh spacing.

7.1.2.2.3 Reynolds-Averaged Navier-Stokes equations (RANS)

If considering a single point in a fluid domain with turbulent flow, and measure any property φ , such as speed or temperature, it will experience a random and fast fluctuations around a mean value. In the Figure 23, we can see the variation of speed in time of a point (Versteeg & Malalasekera, 2007, pp. 66-97).

The nature of turbulent flows, the random variation in speed, produces eddies inside the fluid domain (Versteeg & Malalasekera, 2007, p. 98) (White, 2009, pp. 347-354). These eddies belong to a wide range of sizes, depending also in the Reynolds Number. The DNS captures every detail of these eddies, but it needs applying a high computational effort.

LES models neglect the variations of the small eddies,

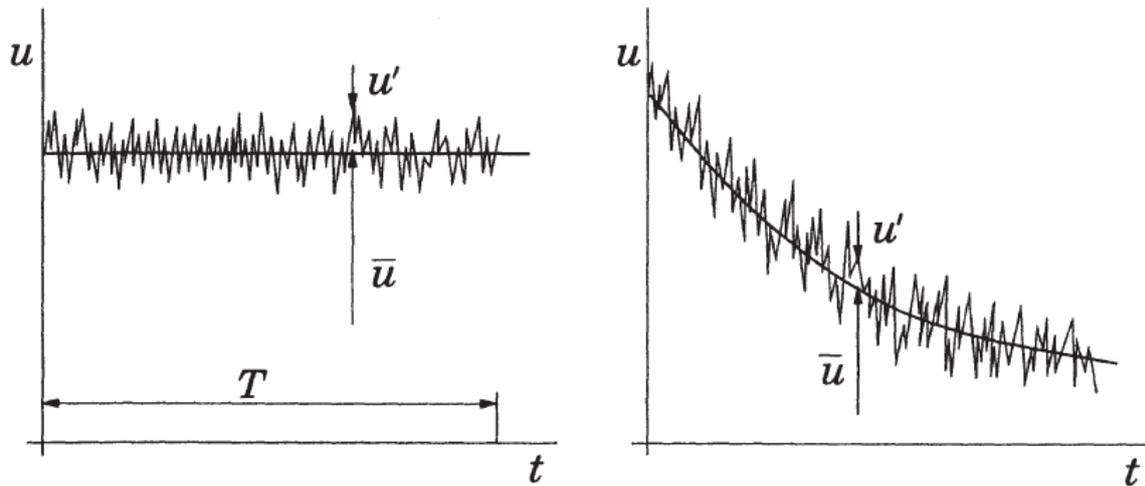


Figure 313. Fluctuations in velocity in a point of a turbulent flow for a steady flow (left) and an unsteady flow (right) (Ferziger & Perić, 2002, p. 293)

The classical approach for dealing with turbulence is using statistical models. These models average the fluctuating properties along a period. And consider the real variations $\varphi(t)$ as a combination of the mean values Φ , and the fluctuations $\varphi'(t)$.

$$\Phi = \frac{1}{\Delta t} \int_0^{\Delta t} \varphi(t) dt \rightarrow \varphi = \Phi + \varphi' \quad (11)$$

Where Φ is the mean value averaged in time, φ is the real value of the property in each time, φ' is the value of the fluctuation in each time, Δt is the period of time where Φ is averaged and $\int_0^{\Delta t} f(t) dt$ is the integral of a time dependent function along the period of time Δt .

Due to its own definition, the average in time of the fluctuations $\varphi'(t)$ is zero.

$$\overline{\varphi'} = \frac{1}{\Delta t} \int_0^{\Delta t} \varphi(t) dt = 0 \quad (12)$$

Based on this, the Navier-Stokes Equations, which define the motion of fluid materials in laminar flows, can be treated averaged in turbulent flows. These equations are called the Navier-Stokes Reynolds-Averaged equations (RANS). And there are several computational models which implement these equations in CFD codes.

This approach is the most common in the industry because, in most of the applications, the mean value of the properties is enough information. Also, the required computational effort for running these models is much less than the other two categories. These models add equations to the default ones for solving the turbulence. They are categorized following the number of equations they add to the actual ones. Using more equations means more accuracy and capability of representing complex flows, but also means more computational

effort. Therefore, the CFD engineer should choose carefully the turbulence model for each application.

When selecting turbulence model there two characteristics that should be considered: the complexity of the flow and the balance accuracy-computational time. The best relation of these two factors, for this project, are the RANS models. The information needed for the design from the flow simulation is not as detailed as the other schemes provide, while the time used is smaller.

Although the group have chosen RANS equation as model for the turbulence, there are several models which use the RANS equations approach. Here, the most popular are presented.

1.1.1.1.1.1 Spalart-Allmaras model

This model adds only one equation for the definition of the turbulence (Versteeg & Malalasekera, 2007, pp. 89-90). This equation is a conservation equation of a variable called kinematic eddy viscosity parameter $\tilde{\nu}$, which is a custom parameter for this model, related with the dynamic eddy viscosity as follows:

$$\mu_t = \rho \tilde{\nu} f_{v1} \quad (13)$$

Where μ_t is the dynamic eddy viscosity, ρ is the density, $\tilde{\nu}$ is the kinematic eddy viscosity parameter and f_{v1} is the wall-damping function $f_{v1} = f_{v1}(\tilde{\nu}/\nu)$, which introduces the variation $\tilde{\nu}$ next to the wall depending on the Reynolds Number. This model has four independent constants to calibrate it for different applications.

This model provides a good definition of boundary layer with adverse pressure gradients. However, due to its single equation, more information must be specified through the constants. Part of this information is related with the geometry, that's why this model it is not suitable for flows with too complex geometry, especially in internal flows, where the flow is much more affected by the geometry. Although its limitation in internal flows, it is widely use in the aerodynamic analysis.

1.1.1.1.1.2 k-ε model

This is one of the most popular general purpose models in the industry (Versteeg & Malalasekera, 2007, pp. 72-76). It only adds two equations and provides a good representation of a wide range of cases.

The k-ε model adds two equations for defining the turbulence. These equations focus on the mechanism which affects the turbulent kinetic energy k . The turbulent kinetic energy is the kinetic energy associated to the fluctuations in speed produced by the turbulence.

$$k(t) = \frac{1}{2} (\overline{u'^2} + \overline{v'^2} + \overline{w'^2}) \quad (14)$$

Where k is the turbulent kinetic energy, u is the velocity in the x-direction, v is the velocity in the y-direction, w is the velocity in the z-direction, x' indicates that the variable is a fluctuation due to the turbulence, and \bar{x} means that the variable is averaged in time.

The other equation is for defining the rate of viscous dissipation ε (see *Engineering Calculation Methods for Turbulent Flow* from Bradshaw et al.). Both variables have its own conservation equation. These equations are added to the solution process for defining the turbulence.

The k- ε model can be adjusted to a certain problem through the values of five constant. These constants are adjusted using experimental data. As the group does not have experimental data, the group has left the default values. These values are proven to be right for a wide range of situations.

1.1.1.1.1.3 SST k- ω model

This model is an improvement of the initial k- ε model (Versteeg & Malalasekera, 2007, pp. 91 - 92). The initial k- ε model predicts the free stream flow accurately, but its performance near the wall fails when there are pressure gradients. For this purpose, a hybrid model is created, where the free stream flow is calculated by the k- ε model and near the wall a new model is created. This is done by introducing a new variable instead of ε .

$$\varepsilon = k\omega \quad (15)$$

With this introduction and other changes to ensure a good transition between both models and a better definition near the wall, a good performance is ensured in several cases. This model is used for general purpose in a great variety of applications.

7.1.2.2.4 Selection of a turbulence model

As mentioned above, RANS models are clearly the best option for this project. Due to its good relationship time-accuracy, which provides less information than the other but it is still enough for this project, using much less time than the others. Therefore, one RANS model should be chosen. The three models presented, k- ε , k- ω and Spalart-Allmaras, are the most popular in the industry.

The Spalart-Allmaras model is not suitable for this project because it fails when it comes to simulate flows in complex internal geometries, which is our case. Both the k- ε and the SST k- ω models are good options for this project. SST k- ω seems to be the best option, but we have decided to use the k- ε . This decision has been taken for two reasons:

- The k- ε model provides a weakest definition with pressure gradients near the wall, something we have in this project. However, this is only the basic k- ε model. We have used the k- ε Realizable model, a variant of the k- ε . It is one of the most general-purpose models used in the industry. It is a more complex model which captures much better complex variation of flow close to the wall. Moreover, the k- ε models use a function called wall function for this purpose as well, explained in the next subsection.

- This is a difficult subject, and as mentioned in the section 1.2 Tasks of the CFD engineer, the experience is something essential in this area. The group has a short experience in CFD, and we have only worked with a reduced number of models before. The model k- ϵ Realizable has been used before by one of our members, which is a time saving advantage when preparing the simulation.

7.1.2.2.5 Wall function

Another difficulty present in the turbulence appears when the flow is close to a solid surface (Ferziger & Perić, 2002, pp. 297-301) (Fluent Inc., 2006, pp. 1258-1274). Solid surfaces stop the flow close to them, as we can see in the Figure 24. This reduction of velocity makes the flow close to the surface slower and reduces the turbulence.

Therefore, there is a transition between this disturbed region and the free stream field called boundary layer. This transition is not well calculated by any turbulent model. As one challenge of the turbulence models is defining the behavior of the flow close to the wall. The two equation models, such as k- ϵ need a supplementary equation for this purpose. There are different options for different cases of these equations.

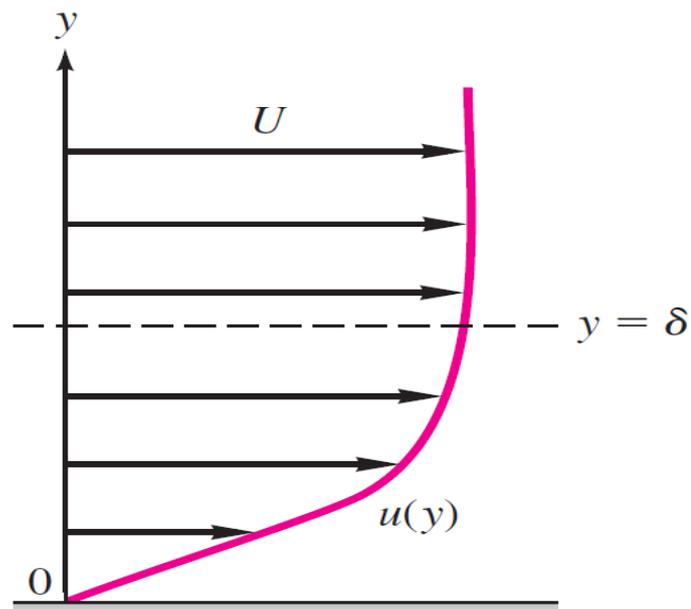


Figure 314. Velocity profile of a boundary layer. U is the main velocity, y is the distance to the wall and δ is the limit between transition and turbulent flow (White, 2009, p. 53)

The most common wall function is the Standard Wall Function because it has been proved successfully in many applications. However, this function has problems in representing non-smooth boundary layers. When the boundary layer gets separated from the solid surface, as in the pictures of the right in the Figure 25, this function does not work properly. The group expected this phenomenon in the project, due to the high difference of pressure, and so, high velocities through the valve. Therefore, the group chose the Non-equilibrium Wall Function, which adds another equation for the definition of the boundary layer. This extra equation helps to capture better more complex flows near the walls.

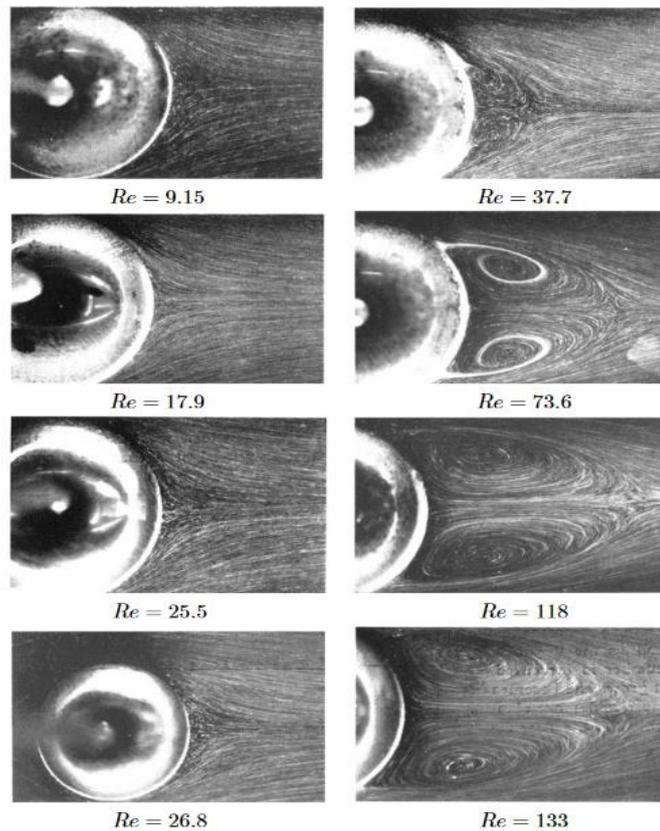


Figure 315. Streamlines of a flow (from left to right) passing a sphere at different Reynolds Numbers. At higher Reynolds we can see how the boundary layer gets separated from the solid faces and makes a recirculation (Brennen, 2005, p. 60)

7.1.2.3 Multiphase

A multiphase flow is referred to a flow where several phases coexist (Ferziger & Perić, 2002, pp. 399-400) (Fluent Inc., 2006, pp. 1599-1605; 1679-1687) (Moran & Shapiro, 2004, pág. 810). This has many applications in industry, from modelling the combustion of coal particles to the flow going out from a spray. There are several models for describing different types of multiphase flow. The group has used the cavitation model.

7.1.2.3.1 Cavitation model

One of the major challenges of our project is dealing with cavitation. Cavitation is the evaporation of the fluid at very low pressures. This means that the group is dealing with flow with liquid and gaseous phases which interact. This interaction, cavitation, must be modelled as well.

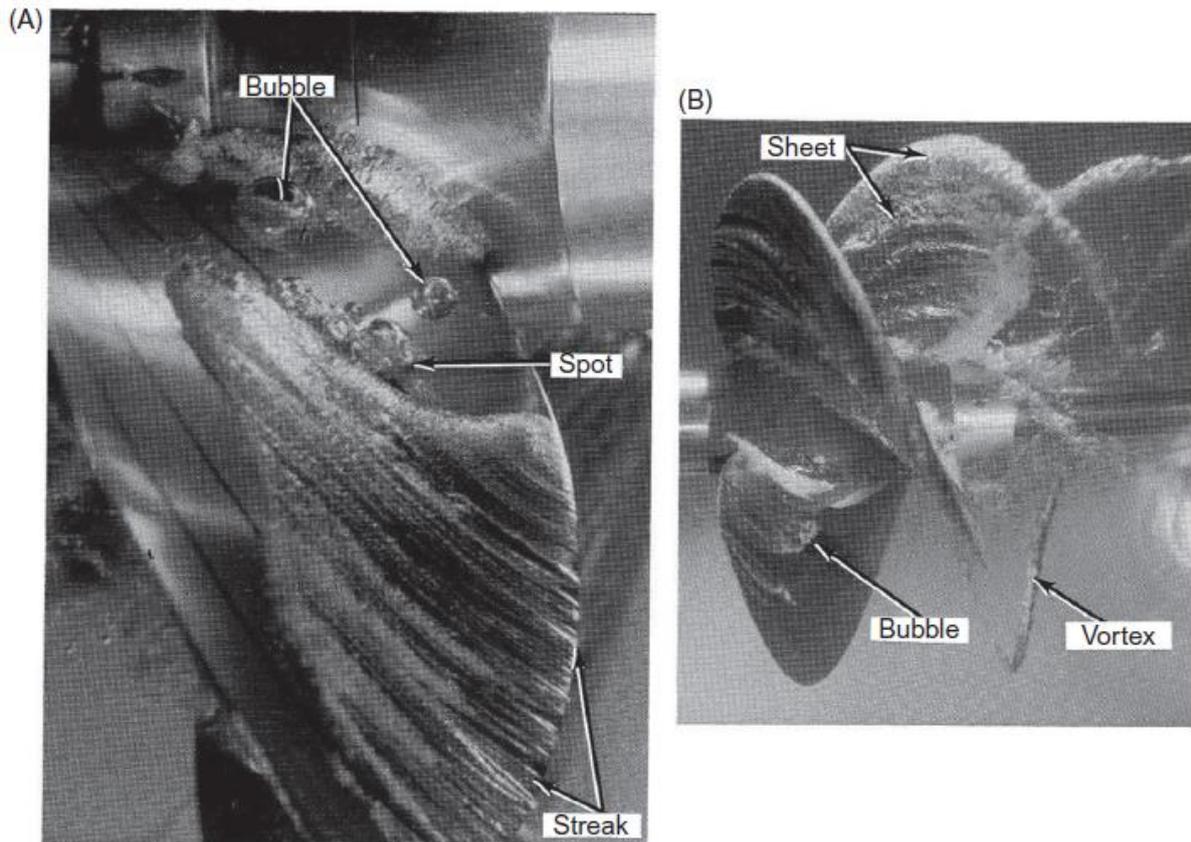


Figure 316. Example of a multiphase flow on a propeller where the water is cavitating in the extreme of the blade (Blake, 2017, p. 13)

A multiphase flow has two ways to be modelled: considering the phases in separated regions with an interface or considering the phases mixed. For our project, the group has chosen a model which considers the phases mixed. The reason is that cavitation is the formation of bubbles inside the fluid domain, and so, vapor and liquid remain mixed. Only in extremely cavitating flows these phases get clearly separated,

The model used for the multiphase definition is Mixture Model. The phase interaction is defined as cavitation, using the cavitation model Schnerr-Sauer. This model calculates the cavitation as if there are non-condensable gases in the fluid domain. And when the pressure gets close to the vapor pressure, the fluid evaporates inside the bubbles of this gases. The model requires definition of the vapor pressure. It is assumed to be constant in this problem, as the variations in temperature are neglectable, and the group has set the value at 4246 Pa, which correspond to the water vapor pressure at 30 °C (Moran & Shapiro, 2004, pág. 810).

7.1.3 Fluids

Each material used in the simulation should be defined. For its definition, a model which defines mathematically the behavior of the fluid must be specified. The simpler the material is defined, the easier is for the solver find a solution. Therefore, the model used for defining a material should be the easiest that represent the physical problem completely. The materials used in these simulations are water liquid and water vapor.

7.1.3.1 Liquid water

As it is an incompressible liquid, the water liquid has been defined as a density constant fluid with the properties:

Properties of water liquid	Values
Density	998 kg/m ³
Dynamic Viscosity	1.00e-3 kg/(m·s)

Table 130. Properties of water liquid at 20 °C and atmosphere pressure (White, 2009, p. 827)

The density and viscosity of water is almost independent of pressure.

7.1.3.2 Vapor water

Due to the cavitation, water vapor may appear in some parts of the simulation. This material has also to be modeled. Due to the inherent nature of cavitation the water vapor will be at very low pressures.

A gas at low pressures, such as the water vapor due to cavitation, can be considered an ideal gas, or even an incompressible fluid, which is preferable as it is the simplest fluid model (White, 2009, pp. 609-615). The compressible effects of gases can be neglected depending on the Mach Number. The Mach Number defines the relation between the speed of the gas and the speed of sound inside this gas.

$$M = \frac{v}{a} \quad (16)$$

The group has calculated the speed of sound using the Ideal Gas Theory. This Theory is a good representation of gases at low pressure, and, as it is cavitating, our gas is at very low pressure.

First, the specific heat ratio for water vapor was calculated. It is a molecule with 3 atoms, so it has 9 degrees of freedom, less 3 for the spatial constrain. With a simple formula the specific heat ratio can be calculated:

$$\gamma = 3 + \frac{2}{f} = 3 + \frac{2}{9-3} = 1,33 \quad (17)$$

And the gas constant of a gas R_m can be calculated with the Universal Gas Constant R and the molecular mass M .

$$R_m = \frac{R}{M} = \frac{8314 \frac{J}{\text{kmol K}}}{18 \frac{\text{kg}}{\text{kmol}}} = 461,89 \frac{J}{\text{kg K}} \quad (18)$$

Now the group applied the formula for acquiring the speed of sound in water vapor at 273 K. This is considered to be the lowest temperature that can be in the system. Therefore, with the lowest speed of sound.

$$a = \sqrt{R\gamma T} = \sqrt{461,89 \frac{J}{\text{kg K}} * 1,33 * 273 \text{ K}} = 401,03 \text{ m/s} \quad (19)$$

As mentioned at the begin of this section, a gas should be considered compressible when the Mach Number is over 0,3. For this case, the Mach Number would be 0,3 when the speed was 123,01 m/s.

It is not expected to get this speed in any part of the system, so the decision is to consider the water vapor as incompressible material. However, this assumption will be validated after the results of the simulation.

The water vapor properties for 20°C and 4246 Pa are as follows:

Properties of water vapor	Values
Density	0,0304 kg/m ³
Dynamic Viscosity	1e-5 kg/(m·s)

Table 131. properties of water vapor at 20°C and 4246 Pa. Density from (Moran & Shapiro, 2004, pág. 810) and viscosity from (ThermExcel, 2003)

7.1.4 Boundary Conditions

Boundary Conditions have a high influence on the development of a CFD simulation. The Boundary Conditions are the values of the variables which are being solved, such as velocity or pressure, in the limits of the simulation domain. These values are necessary for the solver to begin the calculation, as they mean the values where the solution is calculated from. Examples of these conditions are the inlet and outlet.

There are several types of Boundary Conditions. Here, the used boundary conditions are explained.

7.1.4.1 Pressure inlet

In the inlet of the system some variables must be specified: pressure or speed and turbulent conditions (White, 2009, pp. 380-381) (Versteeg & Malalasekera, 2007, pp. 76-78) (Fluent Inc., 2006, pp. 280-286).

In the definition of the problem it is specified that the valve should operate until a pressure of 30 bar. Therefore, the group has defined the inlet of the system with pressure 30 bar.

The turbulent model needs also turbulent boundary conditions. As these models rely on experimental measurements mixed with theoretical approaches, for a very accurate calculation some experimental values should be introduced before. This is not always possible, as in our case, and some guesses and theoretical approaches must be done.

The definition of the variables k and ε at the inlet can be specified in different manners. The best way is giving the values of k and ε directly. As the group does not have the values, an approximation should be done through the turbulence intensity and the hydraulic diameter:

$$D_H = \frac{4A}{P} \quad (20)$$

This is the definition of the hydraulic diameter, where the A is the area of the inlet where the fluid is going through, and P is the wetted perimeter by the fluid considered in the inlet. In our case, the hydraulic diameter matches with the geometrical diameter of the inlet.

$$T_i = \frac{u'}{u_{avg}} = 0.16 (Re_{D_H})^{-\frac{1}{8}} \quad (21)$$

The Turbulence intensity T_i is the relation between the fluctuations of the velocity due to the turbulence u' and the average velocity u_{avg} . This can be related with the Reynold Number referred to the Hydraulic Diameter Re_{Dh} .

With these parameters the variables k and ε can be calculated easily.

$$\varepsilon = \frac{C_\mu^{3/4} k^{3/2}}{0.07 D_H} \quad k = \frac{2}{3} (U_{ref} T_i)^2 \quad (22)$$

Where U_{ref} is the reference speed in the inlet and C_μ is an adjustable constant of the k - ε model which, by default and in our case, is 0.09.

The exact values of the turbulent boundary conditions is not shown, because it has been changing during the design process. Due to the changes in the design and the different models used. But they have been always calculated with the formulas of this section.

7.1.4.2 Pressure outlet

The purpose of our system is dissipating the energy of the water upstream (White, 2009, pp. 380-381) (Versteeg & Malalasekera, 2007, pp. 76-78) (Fluent Inc., 2006, pp. 280-286). This energy is dissipated by reducing the initial pressure, 30 bar, to atmosphere pressure, 1 bar. Therefore, the condition at the outlet should be 1 bar of pressure. And the turbulent conditions can be calculated in the same way as in the inlet. In fact, as both the inlet and the outlet have the same diameter and velocity both have the same turbulent boundary conditions.

7.1.4.3 Wall

The solid limits of the domain are called walls in CFD (Ferziger & Perić, 2002, pp. 297-298). In these Boundary conditions, only the roughness of the wall must be specified, and the group has left the default roughness constant 0.5. The wall boundary condition is defined by zero speed of the fluid which is in contact with it. And for the turbulent boundary conditions, the condition is that the turbulent kinetic energy is zero, due to the null speed, and the turbulent dissipation rate is defined in a more complex way.

7.1.4.4 Symmetry

In our simulation, the group has decided to use symmetry as a way of simplifying the geometry, and so, reducing the computational effort required (Versteeg & Malalasekera, 2007, p. 280). The symmetry condition means that every variable has null gradient in the perpendicular direction of it. The velocity in the perpendicular dimension is also zero.

7.1.5 Mesh adaption

Although the mesh has been set in the mesh module, Fluent has the option to have a dynamic mesh adaption (Fluent Inc., 2006, pp. 2006-2007). This option uses values of the simulation to change the mesh during the calculation. This enables us to adapt the mesh to the preliminary results. It is very useful when the solution is uncertain and the mesh should be adapted to it.

The group has performed the dynamic mesh adaption in two occasions:

One of the models, the one which solves the turbulence, needs a specific distance from the solid walls to the first cell center. This distance depends on the solution, as it depends of the velocity. Making these changes manually could result in a long iterative process, sometimes unaffordable. Therefore, this tool is very appropriate for this purpose. The values in the model can be set to fulfill the requirement. Then, the software changes periodically the size of the cells until the condition is satisfied.

The prediction of the cavitation is one of the goals of this simulation and the group needs to predict it accurately. Using the mesh adaption, the group has oriented the goal of the simulation to get a more accurate result of it. This has been done by refining the mesh where the cavitation is occurring. The mesh has been set to a refined state where the gradient of cavitation passes a certain value. This measure ensured capturing the cavitation properly.

8 Solution

8.1 Solver

The solver is the algorithm the computer follows to solve the discrete equations presented above (Patankar, 1980, pp. 113-117). This algorithm is creating and solving the discretized equations obtained from the Finite Volume Method. There are several solvers, all of them with its advantages and disadvantages.

Due to the non-linear nature of the Navier-Stokes Equations the solution cannot be obtained by solving the algebraic system at once, as the linear FEM does. The solver must follow an iterative process. This means that the discretized equations are solved several times, using a solution of one step to set the following step equations. For a better understanding, the solver could be imagined as a Bisection Method or a Newton-Raphson Method. Where a solution is calculated in each step and compared with the previous one. There are two possible results after comparing them: the difference between them is too high so another iteration must be done, or the difference is acceptable and the solution is converged.

These nonlinear approaches work successfully in a wide range of applications. However, the CFD equations have another difficulty: the pressure. Any variable solved in a fluid problem has its own conservation equation, except the pressure. This equation defines the behavior of the variables along the domain. The pressure is only defined in the momentum conservation equation:

$$\frac{\partial}{\partial t}(\rho u) + \Delta(\rho u \vec{v}) = -\frac{\partial p}{\partial x} + \Delta(\mu \nabla u) + S_{Mx} \quad (23)$$

The pressure is a variable coupled with the speed during the calculation, but it doesn't have its own equation to be solved. It is only represented in the term $\frac{\partial p}{\partial x}$, the gradient of pressure. This is solved creating a pressure equation by reforming the mass conservation equation, but this can be done in different manners. This results in a great variety of schemes used for solving the all the equations. The main types of solvers are presented briefly here.

8.1.1 Segregated

The Segregated solvers make the discretization of the equations and solves them one by one (Ferziger & Perić, 2002, pp. 116-118) (Versteeg & Malalasekera, 2007, pp. 179-190). This means that the velocity is solved first, using the solution of this equation the pressure field is calculated, and then, the rest of the variables are calculated using the pressure-velocity field solution.

The most famous segregated solver is the SIMPLE, Semi-Implicit Method Solver for Pressure-Linked Equations. Which solves the pressure term by creating an equation for correcting the pressure through the mass conservation equation, for more information see (Versteeg & Malalasekera, 2007, pp. 186-192). The scheme of the algorithm is represented in the Figure 27.



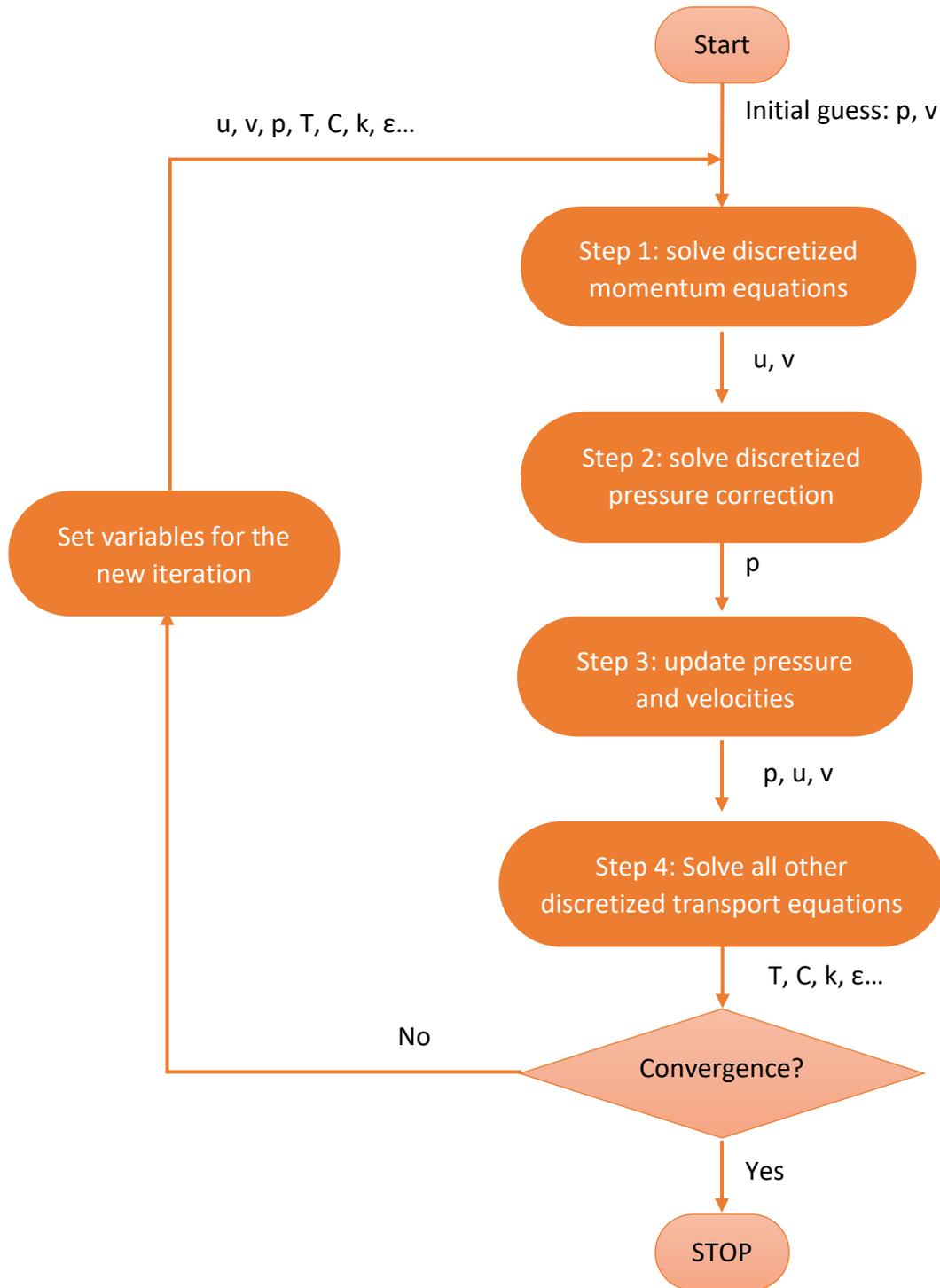


Figure 317. SIMPLE solver algorithm scheme

8.1.2 Coupled

The coupled solvers, as they are named, solve the equations coupled (Fluent Inc., 2006, pp. 1801-1802) (Ferziger & Perić, 2002, pp. 116-118). This means that some equations are solved simultaneously, which result in an internal iterative process. In this process, the results of all the equations must match. The equations that are solved coupled variate in the different solvers. But, mainly, the coupled equations are the pressure and the velocity equations.

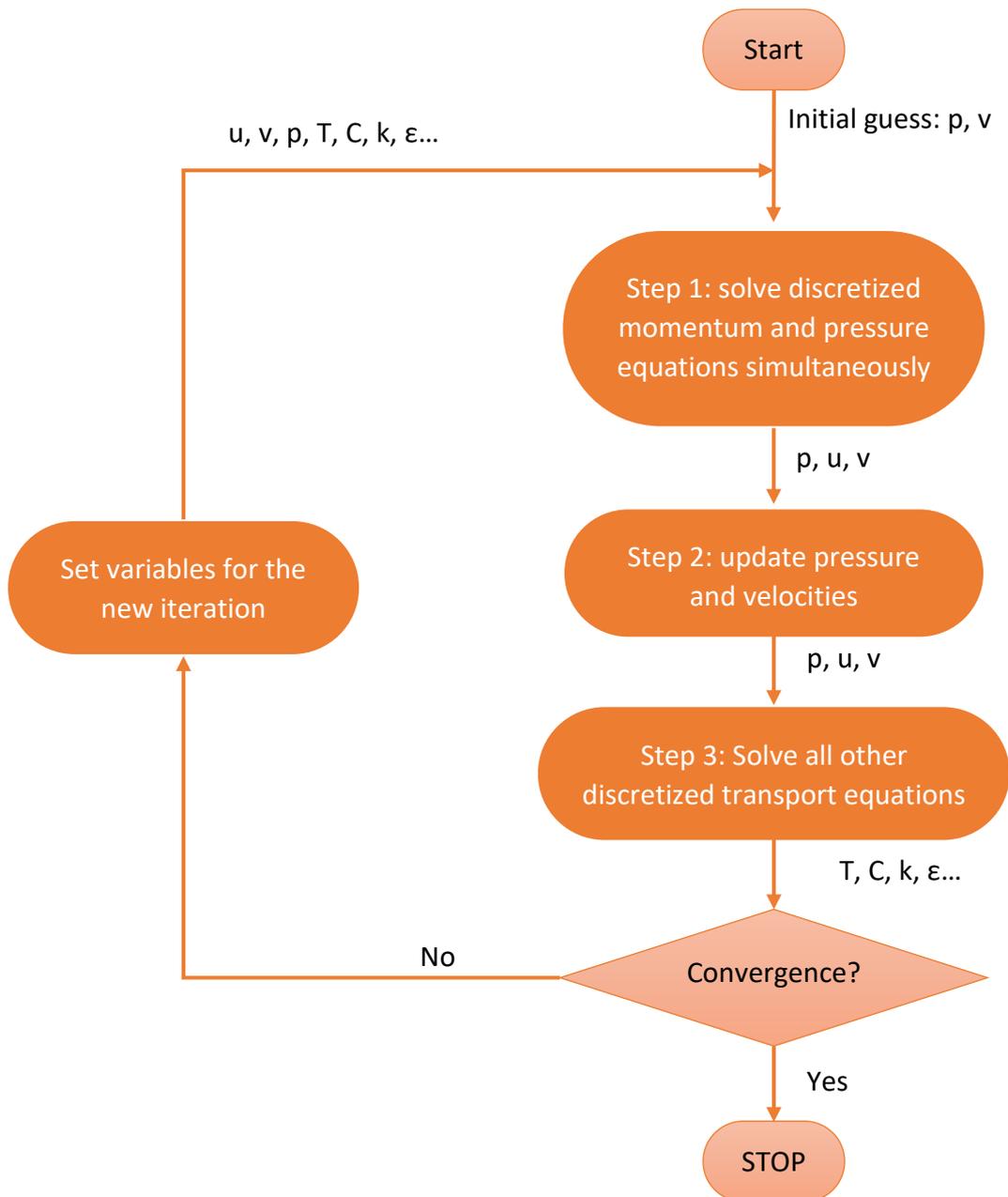


Figure 318. Coupled solver algorithm scheme

8.1.3 Comparison Segregated-Coupled solver

Although the solution given by the two solvers should be the same, there are big differences in the solution process (Fluent Inc., 2006, pp. 1824-1829):

The simultaneous solution of the coupled solvers needs more time to complete an iteration. Contrarily, the segregated solvers only solve each equation once per iteration. This makes the segregated solver to iterate much faster. However, the coupled solver ensures a better solution in each iteration, due to the stronger connection between its solutions. Consequently, the coupled solver has a faster convergence than the segregated solver.

The problem the coupled solver means is its stiffness. The coupled solver needs a better initial guess, or the solution will diverge and the solver will fail. The segregated solver is more flexible, and so, it has a more certain convergence.

In most of the industrial applications, the segregated solvers are used due to its easier convergence. Coupled solves are used in problems where the variations in some variables are very sudden, such as compressible flows with shock waves. These variations make the segregated solver diverge.

The group has mainly used the segregated solver. However, the coupled solver has been applied for the some of the cavitation simulations due to its sudden changes in speed, pressure and phase.

8.2 Methods

As explained, the continuous domain is adapted to a discrete domain. This is done by calculating the variables in some points and interpolating them. For this approximation the FVM has many different schemes, called discretization schemes.

8.2.1 Properties of the discretization schemes

The most important characteristics of the discretization are conservativeness and transportiveness. Applying a continuous variable to a discrete field is a breakthrough task. These properties are related to how well this schemes represent a continuous fluid flow.

8.2.1.1 *Conservativeness*

Conservativeness is the capacity of a discretization scheme for ensuring the mass conservation. In discrete domains, means that the flow through a cell face is the same in the same face of the adjacent cell. This is strongly related to the approximation of the gradient between the cell centers. The better approximation of the gradient the more conservativeness. And, as any interpolation, the more points used for the approximation of one value, the more accurate the approximation will be.

The conservativeness is reduced to the number of points used for the interpolation of the gradients. The number of points a scheme uses is called the grade of the scheme. Fluent offers schemes from the grade one to three.

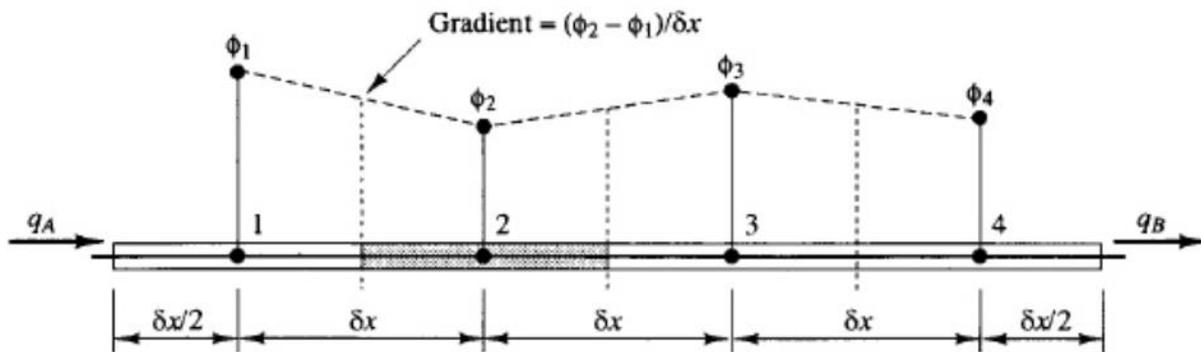


Figure 319. Sketch of the central difference discretization scheme to approximate de gradient of the generic variable Φ on a one dimensional case (Versteeg & Malalasekera, 2007, p. 142)

In the Figure 29, the central difference scheme is presented. This is a second grade scheme, as it uses the two adjacent nodes to interpolate the derivative in the central one. In the Figure 30, we can see a picture a grade three scheme, the QUICK scheme. This scheme represents a better approximation of the gradient.

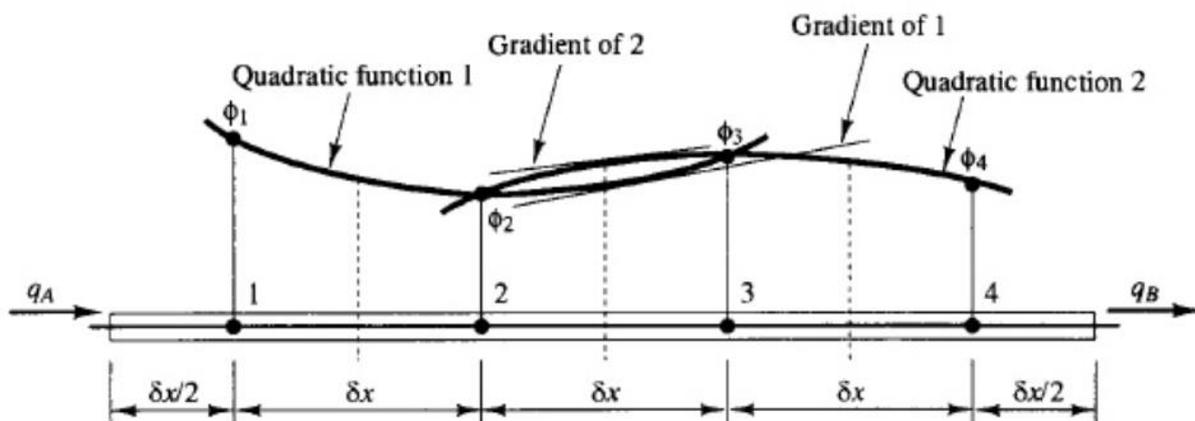


Figure 320. Sketch of the QUICK discretization scheme to approximate de gradient of the generic variable Φ on a one dimensional case (Versteeg & Malalasekera, 2007, p. 142)

8.2.1.2 Transportiveness

The different properties of a fluid are transported, except a few cases, by two mechanisms: diffusion and convection. The diffusion is the transport due to a difference in the values of the variables, for example, a difference of temperatures generates a heat flux. And the convection is the transport due to the velocity of the fluid, such as a dissolved component in a fluid stream. The transportiveness can be explained as the effect a point has to its close points. In the Figure 31, the area of influence of a node in relation with the flow velocity. It is expressed through the Peclet Number:

$$Pe = \frac{\text{convective term}}{\text{diffusive term}} = \frac{\rho u}{\frac{\Gamma}{\delta x}} \quad (24)$$

It is easy to see that, depending on the velocity field, the influence of the node P on the nodes E and W changes tremendously.

The schemes which doesn't consider the direction of the flux, when the convective transport becomes important, become unstable. Central difference scheme is illustrated in Figure 29.

It is an example of a scheme which doesn't consider the direction of the flow. It only approximates the gradient through the interpolation of the adjacent nodes, ignoring the direction of the flux. And this results in unstable solution when the Peclet Number is greater than two. In the other side, the QUICK scheme, illustrated in the Figure 30, interpolates one extra value upstream the node. This extra node provides the discretization scheme a greater robustness.

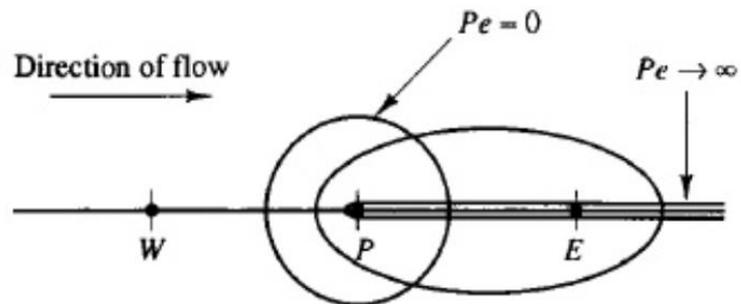


Figure 321. Sketch of the sphere of influence of a node to other due to the velocity direction and intensity. (Versteeg & Malalasekera, 2007, p. 144)

8.2.2 Selection of a method

ANSYS Fluent has several discretization schemes and one of them must be selected for each variable. The preference is always to use high-order schemes, but this is not always possible. High-order discretization schemes have more difficulties in convergence, especially in very complicated problems (Ferziger & Perić, 2002, pp. 78-86) (Versteeg & Malalasekera, 2007, pp. 141-144).

The standard procedure when choosing a discretization scheme is beginning the simulation with the lowest order, and when the simulation is converged, increase one order. And repeat this process until the highest order is reached or the simulation doesn't converge.

8.3 Controls

The iterative process presented in the subsection 8.1 Solver proceeds iteratively. Therefore, the solution obtained in one iteration is used to prepare the following one. This is made by calculating a correction with the actual values and adding this correction to the new ones. This sum means generally a change too big for the equations, creating instabilities in the solution process. This problem is solved by reducing this addition by multiplying it to an under-relaxation factor. This factor is a number between 0 and 1. One under-relaxation factor is set for each equation and can be changed during the solution process.

By reducing the under-relaxation factors the convergence and stability of the solver are improved. However, as the variation between iterations is reduced, the solution process is slower. Therefore, the task of the CFD engineer is finding the right under-relaxation factors,

which provide the necessary convergence without increasing the computational time excessively.

8.4 Report definitions

The report definitions are the parameters which can be defined as output from Fluent to another platform. In our case, these parameters are the necessary ones for the design objectives in the optimization, and validation, of the results.

8.5 Initialization

The iterative solver uses each iteration to set the following one, but the first iteration doesn't have any previous one. Therefore, an initial guess of the variable fields must be done initially. This initial guess is called initialization and it must be taken carefully, as it can mean the difference between convergence and divergence of the solver. The initialization is done using the boundary conditions.

The initialization of the solver is one of the main actual challenges in the CFD research. Nowadays, the initialization is done by the potential flow equations, which don't represent properly the flow. And, when the flow problem involves some complications, this initialization is not enough.

When the initialization is not enough, the CFD engineer should find out a way to provide the solver a better initial guess. This can be done manually, by assigning values to different parts of the domain. Moreover, using data from other simulations is a very good approximation, but it is not always possible.

8.6 Programming solution process

Before applying the solver to an initialized solution, the solution process can be programmed. This improves the performance of a simulation and automates it, allowing the CFD engineer to prepare a queue of simulations without having to pay attention to all of them. This way of working is called Text User Interface (TUI) instead of the Graphical User Interface (GUI). The TUI is written in and uses a dialect of Lisp called Scheme. By this interface the flexibility in the interaction with the solver is much higher than the GUI's one. As the TUI is more complex and slow to learn, the group has only used it when it was necessary. This was when the default initialization of the solver was too poor and/or several queued simulations wanted to be ran.

Some changes have been programmed during the solution process:

- Patch values: as explained in the subsection 8.5 Initialization, the initial solution might be critical. The patch command allows us to assign specific values to a concrete region, but it must be done manually in the GUI. This makes impossible to queue simulations. But the TUI enables us to program the patching.
- Dynamic mesh adaption: due to the limitation of the academic license in the number of cells, it is very important to optimize the mesh. The objective is to have a finer mesh only where it is necessary. Therefore, the solution should be known before adapting the mesh. And the group has programmed the solution to be adapted during

the simulation. It uses the preliminary values for changing the mesh. Then, the solution is run again with the new mesh.

8.7 Run calculation

Running the calculation is the use of the solver. This is done when the setup has been finished and the simulation is initialized. The number of iterations must be specified.

9 Calculation development

During the solution process, as explained in the subsection 8.1 Solver, the solution changes in every step of the calculation until the convergence is reached. As an example, the group has captured the variations of a result during the simulation. The variation of the mass flow rate at the inlet has been plotted against the step of calculation (Figure 32). One can see that it tends to a constant value.

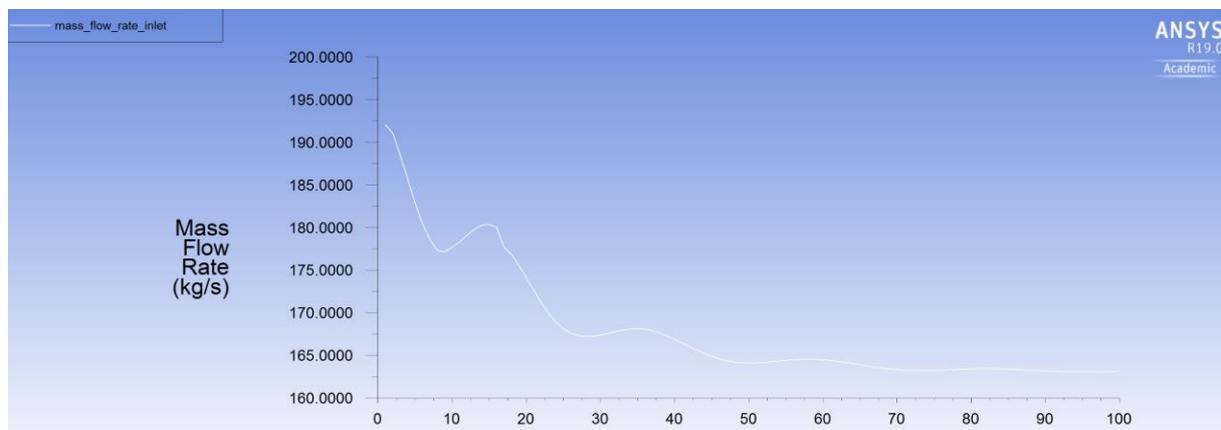


Figure 322. Variation of the mass flow rate at the inlet against through the step of calculation

For controlling this process while it is happening, the solution can be monitored. The monitoring of the solution is done controlling changes between iterations. These variations are called residuals. The smaller the residuals are the better the convergence is. For monitoring the residuals variation, a real-time plot of the residuals is the best tool, used in every CFD software.

These residuals begin at high values, close to 1 generally, and, if the simulations go fine, they go down smoothly. An example of a good variation of the residuals is in the Figure 33.

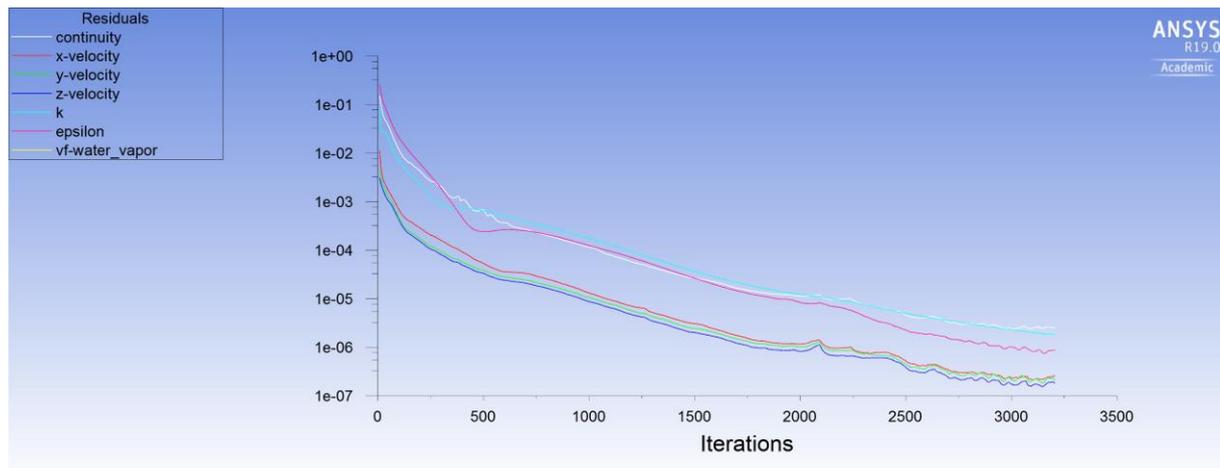


Figure 323. Smooth residuals variations in the interface of Fluent. The legend of the different residuals is at the left upper corner.

The simulation can run forever, so a convergence criterion must be set. The general convergence criterion is waiting until every residual get constant, and they are under 10^{-5} . Some general results can be considered when the residuals are under 10^{-3} , but this criterion can be wrong in several cases. And, for the academic world, the criterion is 10^{-8} for avoiding any possible inaccuracy, but it doesn't worth for the industry because it is too time consuming.

The reasons why a simulation cannot converge are variated and depends on each problem, but in our case, can be divided in three:

- Too poor or coarse mesh: due to the limit of the cells of the academic license, the required mesh size was not achieved in every region. This makes the solver impossible to find a steady-state solution. This happens when the distance between cells is that high, that the variation of values cannot be captured.

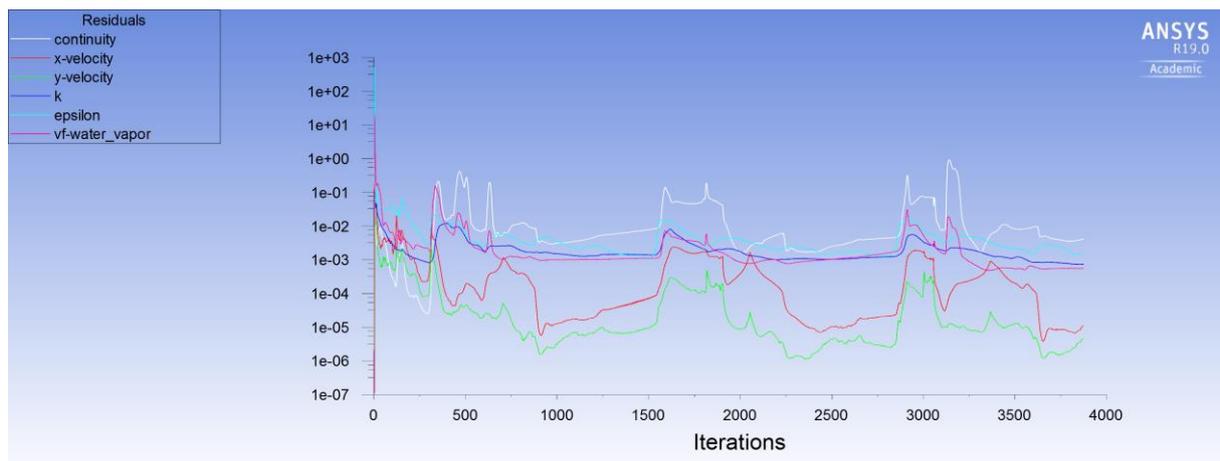


Figure 324. Example of periodical variation of the residuals due to a too rough mesh

- Bad initial conditions: if the initialization of the solver is too far away from the real solution, the solver can diverge. Divergence happens when the residuals are greater than the double number capacity, which means that the results are getting far away

from the real solution. This is especially common with the coupled solvers and in very complex problems.

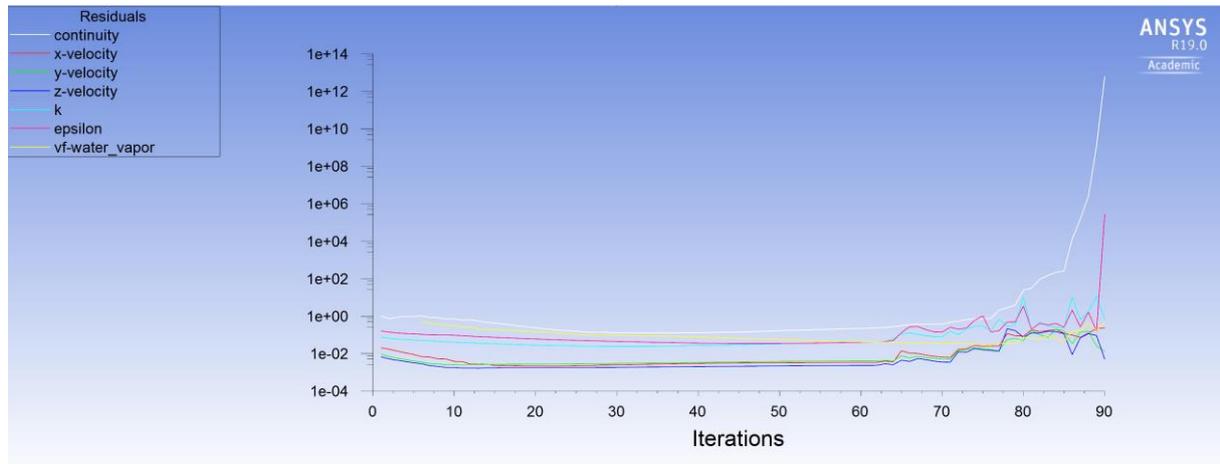


Figure 325. Picture of divergence. The residuals go to very high numbers

10 Results

When the solution is converged, the solver stops and keeps the last iteration values as the final solution. This solution is the values of the variables contained in the models previously defined. And, through these values, the rest of variables of interest are calculated.

These values can be analyzed in different ways. The simplest one is by defining parameters in the software. These parameters are values calculated from the results, such as volume flow rate or the maximum pressure in a surface. This approach is very useful for results which must be quantified. These parameters are useful as well to define relationships between inputs and outputs.

The other approach is by plotting the results. This approach doesn't provide quantifiable results, but it is the best way to see the operating conditions of the problem. This is useful for non-quantifiable results, such as the variations in the direction of the flow through the domain. As we can see in the Figure 32, the streamlines are a good plot to see the direction of the flow in each position, something which cannot be quantified easily.

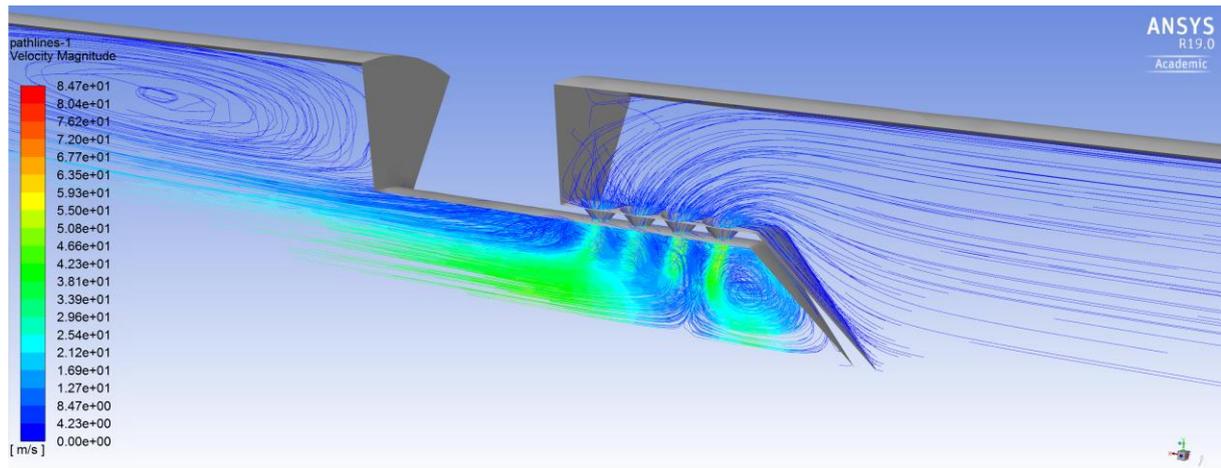


Figure 326. Example of a plot: streamlines which represents the direction of the flow, and the range of colors which represents the velocity magnitude

11 Calibration

When it comes to design an industrial system, several calculations should be done. These calculations are done for different variations of the system. Therefore, a CFD model cannot be a stiff representation of the system. A CFD model must be easily adaptable to any change of the system. So, preparing a model should end in a robust model.

In conclusion, while the setup of a CFD model, the limits of the model should be found and expanded as far as possible. This means finding the limits of the input values which make the simulation fail. By finding these “frontiers” of the system, the CFD engineer will be prepared for any change in the system and will know its model capacity. The further these frontiers are from the actual system, the more robust the model is.

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