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Constructing a Flow Loop for Laboratory Testing of Single Pipe, Batch Based Transport of Production Chemicals

Konstruksjon av strømningssløyfe for testing av metode for undervannstransport av produksjonskjemikalier

Bachelor's thesis written by Dag Olav Snersrud and Herman Brodd

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Summary

The purpose of this thesis is to construct a test rig, designed to further explore the possibilities of subsea chemical injection through a single pipeline. The test rig is constructed at the workshop at SINTEFs Petrotechnical center. It is concluded that the best solution is a closed loop, which in theory is able to simulate infinite pipeline distances. The test rig is compatible with both mechanical and liquid spacers, which is necessary to keep fluids from mixing when transporting different fluids through a single pipe. Furthermore, a set of parameters given by two master students, is used as base for the construction. A variety of different approaches regarding type of test rig is discussed.

Sammendrag

Hensikten med denne oppgaven er å konstruere en strømningssløyfe, designet for å videre utforske mulighetene for injeksjon av kjemikalier subsea gjennom én rørledning. Strømningssløyfen er konstruert på verkstedet på SINTEFs Petrotekniske senter. Det ble konkludert med at den beste løsningen ville være en lukket sløyfe, som i teorien kan simulere uendelige distanser rørledning. Testsløyfen er kompatibel med både solide og flytende avstandsstykker, noe som er nødvendig for å hindre at fluider blandes mens ulike fluider blir transportert gjennom en rørledning. Videre ble et sett med parametere gitt av to masterstudenter brukt som grunnlag for konstruksjonen. Flere ulike løsninger med hensyn på type testsløyfe er diskutert.

Preface

This is a Bachelor's thesis written by Dag Olav Snersrud and Herman Brodd at the Department of Materials Science and Engineering at the Norwegian University of Science and Technology. The submission of this thesis concludes a 3-year Bachelor's degree in Oil and Gas Technology.

We would like to thank our two supervisors, Tor Berge Gjersvik and Marte Sørtveit Mørkve for helpful advisory regarding both academical curiosities, and questions on structure of the thesis. A special thanks is also directed to Kristine Nielsen Berg and Amanda Sofie Opstad, with whom we have collaborated and shared ideas with throughout the process of writing this Bachelor's thesis. Furthermore we would like to thank Noralf Vedvik for his help in the workshop as well as his counsel along our way towards a final product. During the review of the final product, we received help from Roger Overå, and it is therefore nothing but fair to extend a sign of appreciation to him. If it was not for these people, this Bachelor's thesis would not have been what it is today.

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Glossary

The list below provides a definition of academic terms and abbreviations used in this thesis.

Production chemicals = Chemicals used when recovering oil and gas.
Mechanical spacer = Solid device used to separate liquids in a pipe.
Liquid spacer = Fluid used to separate liquids in a pipe.
Umbilical = Cluster of pipes and wires, carrying various fluids and electronics.
Topside = Upper part of an oil production field, above the sea level.
Subsea fields = Area in which oil and/or gas is extracted from the seabed.
Tie-back length = Distance between an existing production facility and a new discovery.
Atmospheric pressure = Pressure within atmosphere of Earth (1 atm = 101325 Pa).
Cavitation = Erosion due to imploding bubbles on metal surface.
Hydrocarbon = An organic compound consisting entirely of hydrogen and carbon, which can be found in crude oil.
RPM = Revolutions per minute.
CAPEX = Capital expenditures.
ID = Inner diameter.
wt% = Weight percent

Chapter 1

Introduction

1.1 Background

The petroleum industry is in constant need for new and better equipment, as well as better procedures for extraction of oil and gas. Every piece of equipment and every meter of a pipe counts when it comes to saving money. However, saving money shall not go at the expense of the safety of the ones working on a platform. It is therefore an important task to reduce the cost of subsea operations without negatively affecting the probability of an accident occurring. To optimize production while ensuring the safety of the crew, the usage of production chemicals has been implemented into the petroleum industry. Currently these chemicals are pumped to distribution tanks and/or manifolds located at the seabed through an umbilical. The umbilical consists of a number of different wires and smaller pipes to feed hydraulics, electricity, and production chemicals to the subsea production site (Bai and Bai, 2010). The electrical, hydraulic, and chemical lines are wrapped up in a protective coating to prevent unwanted fluids and particles to enter the chord. Due to the complex design of the umbilical, it comes with a significant price tag. Therefore, a pull for more cost-efficient solutions exist in the industry. This is especially important at smaller fields placed far away from existing infrastructure, cause then, several kilometers of umbilical is needed (Peyrony and Beaudonnet, 2014).

One way of reducing the price of an umbilical is to remove the lines of production chemicals. But then, a different and more effective way of transporting these chemicals has to be brought into use. In this thesis it is assumed that the production chemicals will be stored in large tanks subsea and refilled upon depletion. It is requested that refilling will be done by a single pipeline where the chemicals are pumped from topside and down subsea in quick succession and separated in the pipe only by either a mechanical or a liquid spacer.

In order to test if this is a possible solution, a test rig is needed, which will be the issue at hand in this thesis - constructing a test rig.

1.2 Scope of Work

Problem Statement

The petroleum industry utilizes a variety of chemicals in processes taking place at the seabed. The chemicals are consumables and the storage tanks on the seabed are routinely refilled from topside. The current refilling process employs an umbilical consisting of a number of different feed hoses for the refilling of the different substances, making the umbilical complex and expensive. To reduce the umbilical cost, it is sought to establish a sequential refilling process that leads all different chemicals through a single feed pipe.

Goal of the Thesis

- Constructing a test rig for laboratory testing of single pipe, batch based transport of production chemicals.

The scope of this thesis is the establishment of a test rig best suited for methodical testing of transport of production chemicals. The test rig is a small-scale simulation of a pipeline, built to provide necessary information to determine if single pipe distribution of chemicals is a viable solution. Chemicals will be sent sequentially in a single pipe and separated by either mechanical or liquid spacers. The rig must be able to provide consistent results regarding test medium and spacers.

For the goal of this thesis to be met, a theoretical research is first conducted. When adequate information on the problem at hand is gathered, different solutions are discussed in order to end up with the best possible result.

1.2.1 Limitations

In this thesis, cost will not be investigated. It will be a focus solely on the construction of the test rig. No further investigation will be done regarding the principles making this single line refueling of chemicals possible. And other than testing throughout the process of making the rig to ensure quality, experiments will not be conducted using the test rig. The test rig is constructed at the workshop at SINTEFs Petrotechnical center, which leads to several limitations including space and realisticity of operating conditions. Due to space limitations, the test rig will be a small-scale simulation of an actual pipeline. Regarding realisticity of operating conditions, the experiments will be conducted at room temperature, and under atmospheric pressure.

1.2.2 Collaboration

The test rig is to be used by two master students at NTNU, in their Master's thesis. It is therefore important to keep a close collaboration with these two particular students, to ensure a product best suited for their need. It is to be used for further development of subsea chemical injection. In collaboration with these students, a set of parameters were decided. These parameters include flow rate, ID of pipe, transparency of pipe, spacer compatibility and length of pipe.

Table 1.1: Parameters for the test rig.

Requirements	
Flow rate	1-2 L/min
ID	0.5-1 inch
Tube property	Transparent
Length	As long as possible
Spacer	Liquid and mechanical

Chapter 2

Theory

In this section, relevant theory is provided to understand the work presented in this thesis. The chapter starts by describing why it would be of advantage to remove lines of production chemicals from the umbilical line. In the next section, usage of production chemicals in the oil and gas industry will be described. Furthermore, the different parts the test rig will consist of will be described. In the chapter's last section, it will be described an approach to choose the best concept that is to be used as a test rig.

2.1 Why Remove Lines of Production Chemicals from the Umbilical?

There are a number of reasons as to why it is wanted to remove the lines of production chemicals from the subsea umbilical. As tie-back lengths increases and subsea fields increases in both size and complexity, the cost of an umbilical is subsequently increasing. Due to this, it is of interest to research whether or not it is possible to transport production chemicals from topside facilities in a different fashion.

An umbilical is installed between the topside facility and the subsea production site. Its main purposes is to provide the subsea facility with hydraulics, electricity, and production chemicals to both operate and control the production subsea. Due to the complexity of an umbilical, it is often one of the largest costs when developing a new subsea field (Bai and Bai, 2010). Estimations show that umbilical costs can be as high as 8-10% of a subsea field CAPEX, as shown in Figure 2.1 and 2.2. If these costs could be reduced, it would be a great advantage when developing new subsea fields.

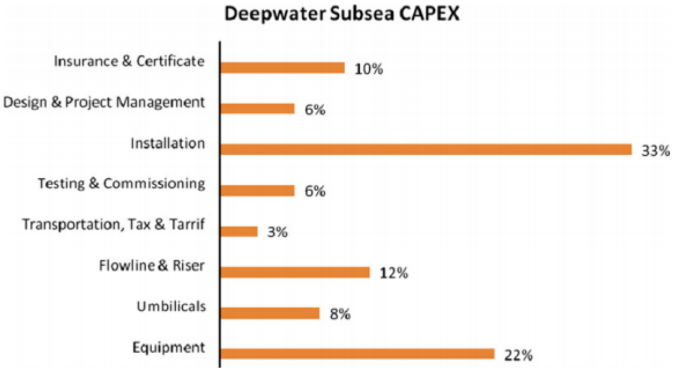


Figure 2.1: Deepwater Subsea CAPEX Breakdown. (Bai and Bai, 2010)

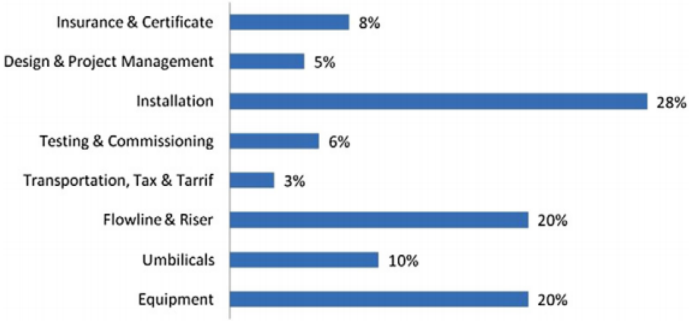


Figure 2.2: Shallow-Water Subsea CAPEX Breakdown. (Bai and Bai, 2010)

Figure 2.3 shows that the longer the tie-back lengths, the more expensive a classical umbilical would be in comparison with a subsea station. A subsea station is a solution for removing lines containing production chemicals from the umbilical. This is based on a case study performed by Total and Doris in 2014 for an oil development case. If the tie-back length is sufficient enough, it would be more cost efficient to use subsea stations and removing production chemical lines from the umbilical (Peyrony and Beaudonnet, 2014). As Figure 2.3 shows, for tie-back lengths longer than 24 km it would be more cost efficient to remove lines of production chemicals from the umbilical.

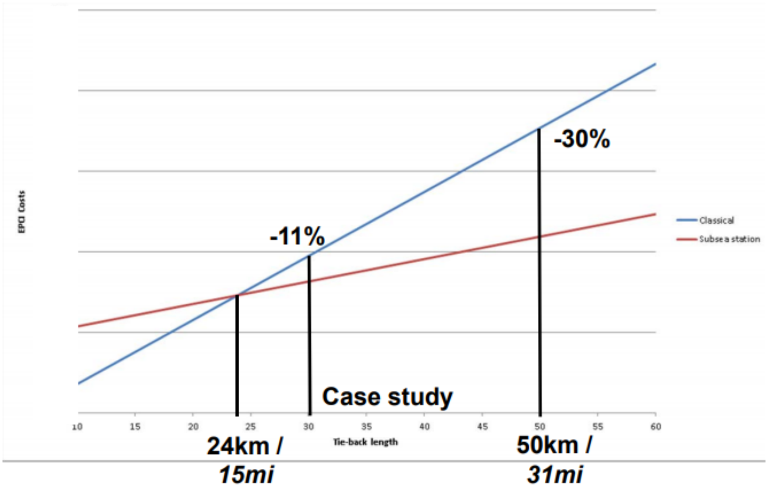


Figure 2.3: Shallow-Water Subsea CAPEX Breakdown. (Peyrony and Beaudonnet, 2014)

2.2 Production Chemicals

Production chemicals are essential to ensure safe and efficient operations subsea. Chemicals are injected into the well stream to avoid pipe blockage and provide best possible flow. Debris and other sorts of matter may clog up a pipe and ultimately lead to a too narrow pipe for fluids to run through it properly. Because of this problem, flow assurance is brought into practice. Flow assurance can be defined as measures done to avoid issues related to flow of hydrocarbons. Common problems associated with flow assurance are for example scales, wax deposits, hydrate plugs, and asphaltenes. Chemicals are therefore injected to avoid such problems and assure optimal flow.

Today, wellhead injection of production chemicals is one of the most usual ways to inject chemicals. When injecting at a subsea wellhead, the chemicals are carried to the wellhead either via a manifold, or directly from the umbilical chord. The injection can be done both continually or periodically, which depends on the quantity of required chemicals. (Kelland, 2014)

The production chemicals role is to minimize issues regarding flow assurance. The different production chemicals may be classified as follows: (Kelland, 2014)

- Inhibitors to minimize fouling and solvents to remove preexisting deposits
- Process aids to improve the separation of gas from liquids and water from oil
- Corrosion inhibitors to improve integrity management
- Chemicals added for some other benefit, including environmental compliance

Type of production chemicals that are injected into the well stream, varies from field to field. Temperature, pressure, and composition of well stream are factors that contribute to the different problems that can occur inside the pipes under operation. Chemicals used for a given field are therefore decided from these factors, and the subsequent problems that occur.

Unwanted matter, which is called fouling, in a pipeline include scales, corrosion products, wax, asphaltenes, naphthenates, biofouling, and gas hydrates. Due to long pipeline distances, this can lead to blockages inside the pipe, which is catastrophic for both safety and economic reasons. There are two general ways to prevent this from happening; use a dispersant or use an inhibitor. A dispersant allows solid particles to form but instead of attaching to the pipe walls, they are mixed into the production stream ensuring no deposits. There are a lot of different inhibitors, but a general definition of an inhibitor is a substance which prevents, or decreases the rate of a chemical reaction.

The separated oil, gas, and water must meet a set of requirements regarding impurities. To help ensure that these requirements are met, production chemicals are used to enhance the performance of the process plant. Chemicals used for these situations are, among others, demulsifiers and antifoams. Demulsification is the process of water and dissolved salts in the water-in-oil emulsion separating from the oil before further transport. Water-in-oil emulsion occurs when water droplets stabilizes in a continuous oil phase. Antifoam are used to control foams. Foams consists of a high-volume fraction of gas dispersed in a liquid (Prud'homme, 1995). This can create several operational problems in two- and three-phase separators.

Issues related to corrosion may affect the structural integrity of the facilities, and therefore also affect the safety and environment. Electrochemical corrosion happens when metal is in contact with water, which happens with the pipe both on the inside and the outside. Corrosion rates varies with factors such as pH-value, temperature, access to O_2, and also in proportion to water-soluble gases such as H_2S and CO_2. To mitigate these issues, injection of different corrosion inhibitors are performed. The inhibitors are injected either by batch or continuously, to keep the corrosion rate within an acceptable level. (Kelland, 2014)

2.3 Valve Types

The experiment in this thesis uses valves, so this section will describe the basics of valves.

A valve is a mechanical device designed to start, stop, regulate, or direct flow, pressure, or temperature of a process fluid. It is used for gas or liquid applications (Skousen, 2004).

2.3.1 Classification According to Function

Nesbitt divides valves into five different types depending on what function they provide. The types are isolating, non-return, regulating, control and safety relief valves (Nesbitt, 2007).

Isolating valves are designed to shut down parts of a system. The purpose for shutting down parts of a system include maintenance and safety. The valve permits maintenance and inspection without shutting down the process and loss of production. It is also fitted at the blank end of lines or manifolds to allow future connection of additional equipment without shutting down operating processes. Examples of isolating valves are gate, globe, and piston valves.

Non-return valves are designed to prevent fluid from travelling the wrong direction in a system. It is often used to protect rotodynamic compressors and pumps, by eliminating any backflow. Reverse flow of fluids can cause machine problems for equipment installed along a pipeline, and a non-return valve will not allow reverse flow. Examples of non-return valves are swing disc non-return, twin disc non-return, and piston non-return valves.

A **control valve** regulates the flow rate. It opens and closes in response to an external signal and is powered by an external source. The external source is either electricity, compressed air, or pressurized liquid. The control valve is a part of an automatic control system, which also consists of the fluid to be controlled, a sensor for the process variable, a controller which affects the actuator, and an actuator which modulates the valve. Examples of control valves are globe, and ball valves.

A **regulating valve** is similar to a control valve, but unlike a control valve, a regulator does not require an external supply of electricity, compressed air, or pressurized liquid. It is self-powered. Regulators are for that reason used where a control valve would be used but external power is not available or when set point deviation is not critical. Examples of regulators are constant pressure, differential pressure, and constant flow regulators.

A **safety relief valve** (SRV) is designed and used to open and relieve excess pressure, and to close and prevent further flow of fluids. It is essential to protect equipment and personnel from higher operating pressures. Excess pressure can also cause material over-stressing, which needs to be avoided. Examples of safety relief valves are spring-loaded safety relief valves, and also vacuum break valves to prevent partial vacuum which can lead to components deforming or buckling. (Nesbitt, 2007)

2.3.2 Classification According to Motion

Another way to classify valves is according to motion. There are two ways for the closure element to activate. Closure element is the term used to describe any internal device used to open, close, or regulate the flow. The closure element either closes by use of linear- or rotary motion. By using linear motion, a valve is pushed into open or closed position by a sliding-stem design. When using a rotating motion, the closure element rotates to open or block the flow.

Linear valves are the most common type of valve in existence today, because of their simple design, easy maintenance, and versatility with more size, pressure class, and design options. Rotary valves are usually smaller in both weight and size than comparable linear valves. However they are limited to certain pressure drops and are prone to cavitation and flashing problems.

Examples of linear-motion valves are gate and globe valves, while ball and butterfly valves are examples of rotary-motion valves. (Skousen, 2004)

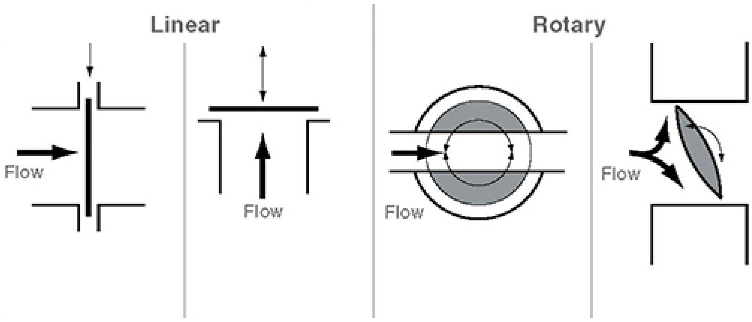


Figure 2.4: Examples of linear- and rotary-motion valves. (Spirax Sarco Limited, 2019)

2.4 Spacer Types

As the name implies, a spacer is used to create a space between different fluids in a pipe to achieve separation. A spacer can be both mechanical and liquid, where as a mechanical spacer is in a solid state, while a liquid spacer is in a liquid state. The two different types of spacers have different applications because of their unlike properties. For example can a liquid spacer be more applicable in a pipe with a series of bends, due to the fact that a mechanical spacer could get stuck in a bend because of its rigidness. An important factor for both spacer types, is chemical compatibility. While a spacer is in use, it will be in direct contact with fluids with different chemical properties. It is therefore crucial that the spacer is prepared for different chemical environments. If a chemical reaction were to occur, it could result in dissolution of one or both ends of the spacer, ultimately leading to failure.

Figure 2.5: Fluids in succession in a pipe, separated by spacers.

2.4.1 Mechanical Spacer

A mechanical spacer is in all simplicity a modification of a pig. Pigs are devices mainly used to clean pipes and remove unwanted deposits along the inside of a pipeline, and comes in many different configurations (Rigzone.com Inc., 2019). This includes all from metal-bodied to foam, polyurethane, or inflatable. In recent years, the possibility of using pigs as spacers to separate liquids apart from each other have become relevant. This to enable single pipe refilling of fluids, which can significantly reduce the cost of a refill. For clarification purposes, pigs will be referred to as mechanical spacers from here on out.

The mechanical spacer, as mentioned above, is a solid device. A mechanical spacer will therefore not mix with pipe fluid regardless of flow rate. The mechanical spacer will ensure separation of fluids, given that a spacer with a suitable diameter is used. If spacer and fluid were to mix, it would compromise the spacers function, resulting in fluid mix up. For a mechanical spacer to work properly, it has to fill the entire cross section area of the pipe. If the spacer's dimension is imperfect relative to the pipe dimension, the different fluids might flow past the spacer. This is an unwanted event, and can easily be avoided by using a more suitable spacer diameter. In addition to this, a mechanical spacer can also have an edge along the outer diameter made of a softer material, working as a seal. The softer material will compress, resulting in a tighter seal, which ensures that no fluid passes the spacer (Rigzone.com Inc., 2019). It is important that the seal is kept below a given thickness to avoid blockage of the pipe. If the total diameter of the spacer and seal is too large, the friction force created would be too high for a fluid to be able to keep its velocity. This is greatly affected by what kind of pumps that are in use, but in general it is preferable to have as little friction as possible. Efficiency is key.

Figure 2.6: Mechanical pigs used to remove deposits along the inside of a pipe line. (HORIZON Industrial Pty Ltd, 2015)

2.4.2 Liquid Spacer

A liquid spacer is the collective name used to describe any form of spacer made by using a substance in liquid state. The composition of a liquid spacer varies, and have different properties based on the purpose it is made for. To ensure complete separation of fluids, viscosity is an important parameter to keep in mind whilst talking about liquid spacers. The viscosity of a fluid greatly affects both the ability to flow through pumps and the ability to create a constant, laminar flow. In essence, viscosity is defined as the quantity that describes a fluid's resistance to flow (Elert, 2019). If the spacer liquid is too viscous, the spacer could block the pipe, while on the other hand if the spacers viscosity is too low, it will not have enough resistance to fully separate fluids. An example of a liquid spacer is Xanthan gum, which is a water-based solution (Fjeldsaunet, 2018).

Figure 2.7: Fluids with different viscosity. Fluid one (blue) have a low viscosity, while fluid two (yellow) have a high viscosity. (All Pumps Sales & Service, 2015b)

The viscosity of a fluid is not necessarily a constant value. It is rather a variable depending on different parameters such as temperature, pressure, and other fluid properties. Newtonian fluids have a viscosity independent of strain rate, which means that no matter the flow characteristics, the Newtonian fluid will remain with a constant viscosity (RheoSense Inc., 2019). On the other hand, the viscosity of non-Newtonian fluids are changing as a function of strain rate. This fluid property is beneficial in different aspects of oil and gas industry. One example is shear thinning and shear thickening drilling fluid used to gather particles after drilling. If a spacer made of a non-Newtonian fluid is to be used, it is important to consider the strain rate. If strain rate is not accounted for, the result could be a too high change in spacer viscosity, which then again can result in mix of fluids.

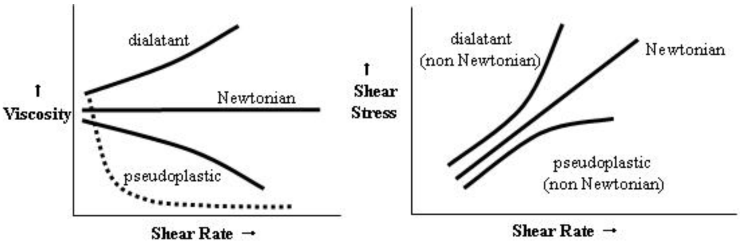


Figure 2.8: Left: Displays viscosity plotted as a function of shear rate. Right: Shows shear stress plotted as a function of shear rate. (FIMMTECH INC., 2010)

2.5 Pump Types

A pump is a device that moves a fluid by improving its energy level. By raising the fluid pressure, the velocity of the fluid increases from the inlet to the outlet. Pumps are generally divided into two groups, based on how energy is added to the fluid. This classification system provides two major categories; dynamic and positive displacement (Forsthoffer, 2006).

2.5.1 Dynamic Pump

A dynamic pump increases the pressure of the fluid by using rotary blades to increase the fluid velocity (Forsthoffer, 2006). Dynamic pumps can be further divided into centrifugal, and other special-effect pumps (Karassik et al., 2008). In this section, centrifugal pumps will be covered.

A centrifugal pump is a rotating machine in which flow and pressure are generated dynamically. Fluids move through the center of a constantly rotating impeller. The centrifugal force applied from the impeller pushes the fluids to a higher level of pressure, and thus increasing the fluid's velocity (Karassik et al., 2008).

Centrifugal pumps are further divided into three categories depending on motion to the pumped liquid. These categories are axial flow, mixed flow, and radial flow. As the name imply, in axial flow pumps the fluid flows along the pump drive shaft. Radial flow pumps generates radial motion to the liquid pumped, while mixed flow pumps gives both. Most centrifugal pumps are of radial flow (Wahren, 1997). The most common problems related to usage of centrifugal pumps are cavitation, wear of impeller, corrosion, and overheating due to low flow (Pump Module, 2007). These are problems that all cause unnecessary cost if the wrong type of pump is chosen. To overcome these problems, tools for analyzing, or simulating the flow that is to be pumped can be used in order to find the best suited pump for a given situation.

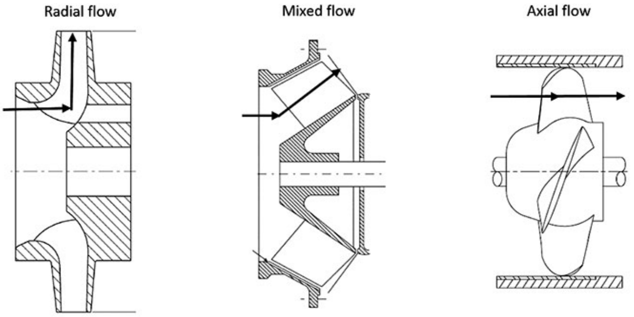


Figure 2.9: Displaying the categories of centrifugal pumps - radial, mixed, and axial flow. (CAHABA MEDIA GROUP, 2019)

2.5.2 Positive Displacement Pump

A positive displacement pump increases the pressure of the fluid by operating on a fixed volume of fluid in a confined space. The pump separates parts of the fluid in a working chamber and subsequently reducing the volume of said working chamber. Positive displacement pumps can be further divided into reciprocating and rotary types, depending on the nature of movement of the pressure-producing members. The pressure-producing member is the component that reduces the volume of the working chamber. (Wahren, 1997)

Reciprocating type increases pressure by use of pulsating action. Fluids are trapped in a chamber, while a piston or a diaphragm pushes down on the fluids which reduces the volume of the working chamber. A valve is opened by the outlet, and the reduced volume inside the working chamber leads to increased pressure in the fluids. Examples of reciprocating pumps are piston, plunger, and diaphragm pumps. (Wahren, 1997)

Rotary displacement pumps has a rotary displacement element. While the displacement element rotates, fluids will fill up between the dividing elements. The displacement element pushes the fluids through the pump, and velocity of the fluids increases from the inlet to the outlet. Examples of rotary displacement pumps are screw, vane, gear, and peristaltic pumps (Karassik et al., 2008).

Screw pumps, vane pumps, and gear pumps are very much alike, and the most defining difference is the pump element. The pump element uses the same mechanism, but with different appearances (Encyclopædia Britannica Inc., 2019), as shown in Figure 2.10.

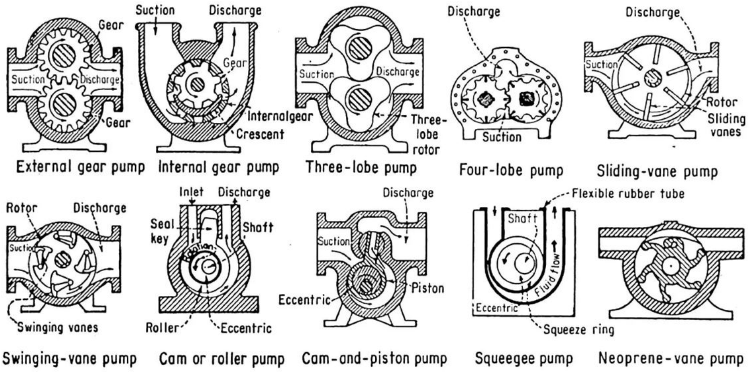


Figure 2.10: Displaying different types of positive displacement pumps.
From left to right, top row: External gear pump, Internal gear pump, Three-lobe pump, Four-lobe pump and Sliding-vane pump.
From left to right, bottom row: Swinging-vane pump, Roller pump, Com-and-piston pump, Squeegee pump and Neoprene-vane pump. (Designed & Engineered Pumps, 2018)

The peristaltic pump also uses a rotary element, but in a different configuration. The rotary element pushes fluids through the tube from inlet to outlet in a circular motion. In essence, a peristaltic pump consists of an inlet, outlet, tube, rotary element, and a casing. And here, the fluid is not in direct contact with the mechanical parts, due to the tube inside. The fact that there is no contact between fluid and pump can be advantageous when there are hydrocarbons in the flow. Hydrocarbons have a tendency to increase corrosion rates, which is an unwanted event. By separating the flow and mechanical parts of the pump, the risk of corrosion decreases drastically to a point where it is no longer an issue. Different pumps may have a problem with corrosion over time, which can result in failure and high costs due to a higher necessity of maintenance. (Verder International B.V., 2019)

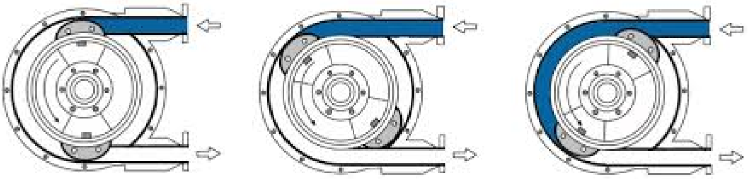


Figure 2.11: Mechanism of a peristaltic pump. The rotary element pushes the fluid through the tube in a circular motion. (All Pumps Sales & Service, 2015a)

When a peristaltic pump is running, the rotating part of the pump reduces the cross section area of a point along the tube inside the pump to approximately zero. This reduction in cross section area makes the fluid inside the pump divide for a short period of time. In the long run, this constant separation that happens in the pump may lead to a mixing of spacer and test medium if not accounted for. To overcome this problem, a large amount of spacer can be used. Having a longer section of a pipe filled with a liquid spacer enables separation of fluids even though the peristaltic pump creates a slight mix in each end of the spacer.

2.5.3 Flow Characteristics

The two categories, dynamic and positive displacement pumps, provides a wide specter of different flow characteristics. A peristaltic pump has a highly controlled way of driving fluids through a pipe, which also goes for for example gear pump and twin screw pump. Other types could possibly create turbulence and have a higher probability of mixing fluids. In the field of fluid dynamic, flow is divided into 3 different patterns - laminar, transitional, and turbulent flow (LiveScience, 2014). Laminar flow can be defined as flow where a random particle in the flow follows a straight line parallel to the direction of flow (The Editors of Encyclopaedia Britannica, 2019). The flow is smooth and with a high level of order in comparison to turbulent flow. Turbulent flow is highly chaotic and particles in the flow moves in all directions which makes it harder to control. Between these two flow patterns, transitional flow can be found. Transitional flow is in all simplicity a transition from laminar to turbulent flow, hence the name transitional flow.

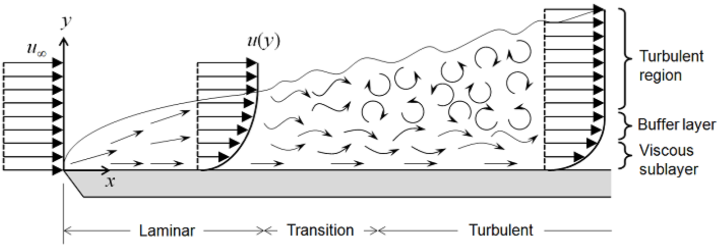


Figure 2.12: Shows laminar, transitional, and turbulent flow. (SU2, 2019)

The different available pumps create different flow patterns, and is therefore an important aspect that has to be considered when choosing pump for a job.

2.6 Concept Scoring

2.6.1 Importance of Concept Selection

Concept selection in an early stage of a design project is of critical importance. In the early stages, it is often a large number of different design concepts. If chosen correctly it greatly influences the cost, robustness, manufacturability, and development time of the final product.

The Concept Scoring Selection Method is utilized to narrow down a set of concepts, and eventually choose the assumed best concept. The Concept Scoring Selection Method ranks the concepts up against each other, and are judged by the same criteria.

2.6.2 Concept Scoring Selection Method

To select the correct concept, a method called Concept Scoring Selection Method is used. The method uses a scoring matrix to evaluate concept alternatives. Criteria are chosen subjectively based on design requirements. The criteria are assigned a weighting, dependant on how important the criterion is to the final product. A percentage is normally used to assign the weight. Concepts are given a rating from 1 to 5, where 1 is worst and 5 is best, on each of the criteria. Once all the concepts are rated, a total score for each concept is calculated, shown in Equation 2.1:

$$TotalScore = \sum_{1}^{n} w_n * d_n \tag{2.1}$$

Where n is the count of criteria, w_n is the weight of nth criteria, and d_n is the rating of the nth criteria.

The concept with the highest total score is assumed to be the best concept, given the criteria and their weighting. (Xiao et al., 2007)

2.6.3 Criteria

To select the best possible concept, five criteria is chosen. The criteria is decided from the given requirements, and from factors deemed important to solve the thesis' goal. The requirements are shown in Table 1.1. The criteria chosen are manufacturability, reliability, spacer compatibility, realisticity, and testing volume.

Manufacturability is chosen as a criteria to evaluate how difficult it is to build the rig.

Reliability is of great importance to the rig. It may need to be running experiments for an extended period of time without failure. This is needed to achieve accurate results, hence the importance of reliability as a criterion.

It is specified in the design requirements that it is expected of the rig to be compatible with both liquid and mechanical spacers. The concepts will therefore be evaluated against **spacer compatibility**.

When conducting experiments to replace existing solutions in the industry, it is important that the experiment is realistic. **Realisticity** is therefore brought in as a criterion to determine whether or not the rig resembles a real life scenario.

A high amount of **test volume** will result in a higher likelihood of correct results rather than a low amount of test volume. To simulate larger volumes, the rig can also have seamless replacement of chemicals and spacers.

The criteria is weighted from 0% to 100%, or when inserted in Equation 2.1, 0 to 1. The weight of each criteria is inserted as w_n in Equation 2.1. In Table 2.1-2.3, it is explained the weighting given the criteria.

Table 2.1: Description of parameters given the weighting 0% to 35%.

Criteria	**Description of weighting from 0% to 35%**
Manufacturability	The rig is close to impossible or challenging to build
Reliability	The system fails often and results are inconsistent
Spacer compatibility	Can neither use liquid nor mechanical spacer
Testing volume	Testing volume is insufficient and will greatly affect the quality of results
Realisticity	The rig is not reflecting a real life scenario at all

Table 2.2: Description of parameters given the weighting 35% to 70%.

Criteria	**Description of weighting from 35% to 70%**
Manufacturability	The rig is of intermediate difficulty to build
Reliability	The rig occasionally fails and results are consistent to a certain degree
Spacer compatibility	Can use either liquid, or mechanical spacer
Testing volume	Testing volume is adequate, but for quality results a higher volume is needed
Realisticity	The rig does in some degree resembles a real life scenario

Table 2.3: Description of parameters given the weighting 70% to 100%.

Criteria	**Description of weighting from 70% to 100%**
Manufacturability	The rig is easy to build
Reliability	The rig seldom or never fails, and results are consistent.
Spacer compatibility	The rig is compatible with both liquid and mechanical spacer
Testing volume	The rig is large enough to contain necessary chemicals and spacers, giving quality results
Realisticity	The rig closely resembles a real life scenario

2.6.4 Scoring

To select the best concept, it is important to choose the correct rating for each criteria. The rating for each concept is inserted as d_n from Equation 2.1. The rating varies from 1 to 5, where 1 is worst and 5 is best, as shown in Table 2.4.

Table 2.4: Definition of ratings, d$_n$, for each criteria.

Rating	Definition
1	Insufficient
2	Below average
3	Average
4	Above average
5	Excellent

Chapter 3

Description of Concepts

In this chapter, the different concepts will be described. An assumption made for all concepts is that they must be capable of containing at least two spacers and fluids. Furthermore, the rig will operate at room temperature and in atmospheric pressure. All pipes in these concepts are to be transparent, to enable visual observation when conducting experiments. The most important factor to keep in mind for all concepts is that it must be possible to simulate infinite distances of pipelines. This is reflected in every concept presented. In real life this means that the rig can be stopped after a wanted period of time, when the simulation have reached its goals. In other words- there will be no upper limit concerning simulated testing distance. It is preferable that the rig supports seamless injection of spacers while running.

The figures presented in this chapter are only sketches to help visualize the concepts.

In order to come up with different concepts and proposals for a test rig, a process of thoughts, meetings and conversations have been made. For every concept it starts with a simple sketch and an idea, and if the idea shows promise, it is taken to the next step, which is a meeting with the supervisors. If the concept is not discarded in an early stage, it is is brought into the thesis in a more detailed fashion, Figure 3.1. The different concepts up for evaluation are listed and gone through in detail in the following sections.

Figure 3.1: Flowchart illustrating chain of events in the process of creating concepts

3.1 Concept 1, "Bicycle Wheel"

This concept is based on relative motion between the pipe and fluid. A circular pipe connected to a motor will rotate like a wheel to simulate long distances of pipes. The number of spacers needed are locked into place by magnetizing the spacers and placing magnets on the outside of the pipe. To achieve the wanted position of a spacer, magnets are placed along the outside of the pipe, above the wanted spacer location. Because of the magnetic force, the spacers will be kept in the same place, given that the magnet is strong enough to withstand the other forces acting on the spacer as the wheel spins. Because of the spacers, fluids in the pipe will remain in the same position relative to the observer. This, however, will not be the case for the relative motion between the pipe and fluid. While operating, the pipe will rotate around the fluid, which will simulate a fluid traveling a given distance in a pipe.

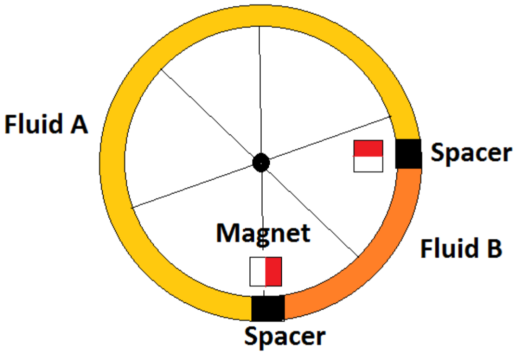


Figure 3.2: Simple sketch of Concept 1, "Bicycle Wheel".

Table 3.1: Displaying positive and negative qualities of Concept 1, "Bicycle Wheel".

Pros	Cons
+ Easy to build	- Not realistic
+ Reliable	- Only works with mechanical spacer
+ Easily adjustable RPM	- Strictly limited testing volume

3.2 Concept 2, "Rotating Staff"

This is the only concept that does not include a loop, and instead of using a loop, this concept takes use of a straight pipe connected to a rotating motor. The rotation point, and also the point where the pipe will be connected to the motor, will be at the center of gravity of the empty pipe. A spacer is placed inside the pipe, and fluids are placed on both sides of the spacer. When the motor is running, the pipe will rotate and fluids will go back and forth inside the pipe, creating a relative motion between the fluids and pipe.

For this concept to work, the rotation of the shaft can not exceed a given RPM. If the shaft rotates faster than the allowable RPM, the fluids will be pushed to each end of the pipe, due to centrifugal force. It is therefore important to rotate the pipe below a given RPM, and that the centrifugal force is significantly lower then the gravitational force acting on the test medium.

This concept does not enable insertion of spacers nor liquids while the rig is running, but it is easy to build.

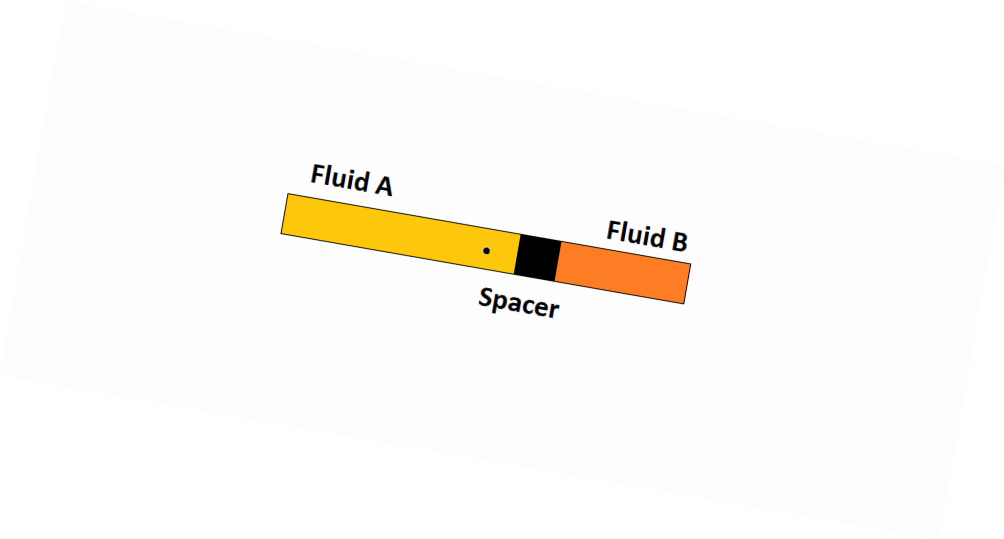


Figure 3.3: Simple sketch of Concept 2, "Rotating Staff".

Table 3.2: Displaying pros and cons of Concept 2, "Rotating Staff".

Pros	Cons
+ Very easy to build	- Highly unrealistic
	- Unreliable
	- Insufficient testing volume
	- Only works for mechanical spacer

3.3 Concept 3, "Circular Loop, Version 1"

This concept is more traditional compared to the previous two concepts, because the fluids and spacers will be the only moving part of the rig. A pipeline will be put together with a pump as the driving force, and the fluid will be sent in a circular motion. The test rig will consist of one pump, one injection location, one extraction location, and pipes to bind it together as a unit. To enable insertion of spacers while the rig is running, a bypass solution is introduced in this concept. The bypass is shut off from the rest of the pipe with a valve, and only opened if extra spacers are needed.

The test medium will flow in a circle, and under normal conditions the bypass pipe will not be used. If it is wanted to inject a new spacer into the pipe, a spacer is loaded into the bypass manually, and valves are opened to force the fluid through the bypass. The result of this is that the new spacer is carried by the fluid into the main pipe. As soon as the test medium and spacers are clear of the bypass, valves on both sides of the bypass are closed. The test will then continue in the inner circle, and if needed, the same procedure can be done again to include another spacer. This concept only works for liquid spacers, because it does not include a device to enable mechanical spacers to bypass the pump.

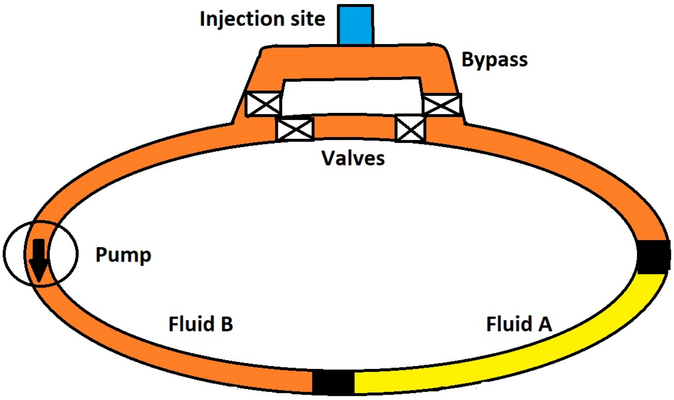


Figure 3.4: Simple sketch of Concept 3, "Circular Loop, Version 1".

Table 3.3: Shows pros and cons for Concept 3, "Circular Loop, Version 1".

Pros	Cons
+Realistic	-Only compatible with liquid spacers
+Relatively easy to build	
+Sufficient testing volume	
+Reliable	
+Allows for seamless spacer injection	

3.4 Concept 4, "Circular Loop, Version 2"

The main loop in concept 4 is the same as in concept 3, and the only difference lies in the method used for spacer injection. The fluids are powered by a pump, to ensure continuous flow at all times. Because of the similarities to the previous candidate, the main loop will not be gone through in detail, and it will rather be a focus on the different approach to the injection of spacers.

Spacers will be injected by using a bypass, similar to concept 3, but a different way of injection will be put into use. While operating, the test medium will flow through the main loop as usual. When a spacer is to be injected, it is loaded into the lower section of the bypass and the two valves located in the bypass pipe will open. At the same time, the valve in the main loop will close, Figure 3.5. This forces the fluid to go through the bypass and back into the main loop. While the fluid is passing through the bypass, the new spacers is brought with the flow. After the spacer injection sequence is finished, main valve is reopened and the two bypass valves are closed, forcing the fluid back into the main loop. This procedure can be done as many times as number of spacers loaded into the spacer launcher, given that there is a sufficient volume available in the loop. If too much of the volume is taken up by fluids, it is required to empty some of the pipe to make room for another spacer.

Similar to concept 3, this concept does not include a device to enable mechanical spacers to bypass the pump, and is therefore unable to use mechanical spacers.

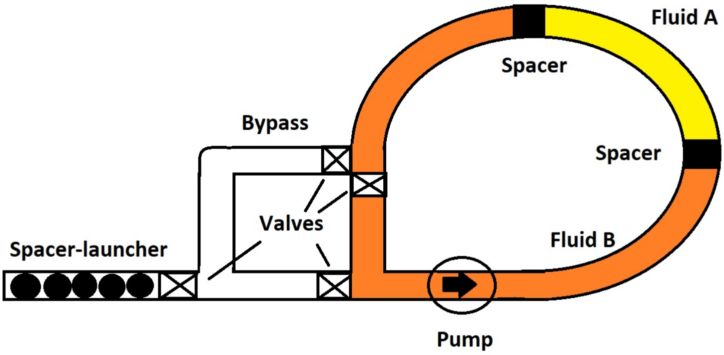


Figure 3.5: Simple sketch of Concept 4, "Circular Loop, Version 2".

Table 3.4: Displaying pros and cons of Concept 4, "Circular Loop, Version 2".

Pros	**Cons**
+Realistic	-Challenging to build
+Sufficent testing volume	-Only compatible with liquid spacer
+Allows for seamless spacer injection	-Less reliable due to complexity

3.5 Concept 5, "Circular Loop, Version 3"

This is a also a circular test rig. The rig will take use of two pumps to achieve flow of both fluids and spacers.The mechanical spacer cannot pass through the pumps, which is a problem. To solve this, a strainer solution is presented in this concept. It will consist of a valve, two pumps, a bypass pipe, and strainers. This to enable the separation of fluid and spacer as the spacer is approaching either one of the pumps.

As shown in Figure 3.6, the valve is located inside the pipe, while the pump is located within an expansion of the pipe. The strainers are axial to the pipe, to ensure that no mechanical spacers enters the pump.

The valve should only be opened when a spacer is approaching. This is to force the fluids through the pump to utilize the pump to full capacity. When the spacer is approaching, the valve needs to open to let the mechanical spacer through. If the valve is closed, the spacer will stop and therefore lose its functionality. This will also result in mix of fluids, and thus compromising the experiment.

While the spacer is located above the pump, the only force making sure that the spacer is kept in motion is the inertia of the fluid. Therefore, the rig is powered by two pumps. This is to remove the possibility of a spacer losing its velocity as it passes a pump. The fluids and spacers will travel through the pipe to simulate a given travel distance in a pipe.

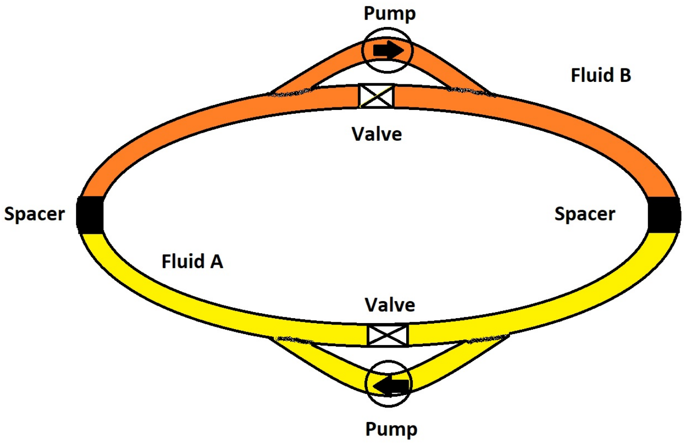


Figure 3.6: Simple sketch of Concept 5, "Circular Loop, Version 3".

Table 3.5: Shows pros and cons of Concept 5, "Circular Loop, Version 3".

Pros	Cons
+Realistic	-Can be challenging to build
+Reliable	
+Sufficient testing volume	
+Compatible with both liquid and mechanical spacer	

Chapter 4

Results

In this section, the concepts are to be evaluated against the Concept Scoring Selection Method using Equation 2.1 for concept scoring. This is done to ensure that the best concept possible is chosen.

4.1 Criteria Weighting

In order to decide which of the concepts presented earlier that will be constructed, the Concept Scoring Selection Method is brought into practice. Before the scoring method can be used, the score weighting must be determined. The weighting concerning each criterion is decided based on the parameters and assumptions that has been made for this particular thesis. The weighting score will be a number between 0 and 1, where 0 means that the criterion is non important, while on the other hand, 1 indicates that the criterion is of great importance.

Table 4.1: Importance of criteria, w_n.

No.	Criterion	Weighting
1	Manufacturability	0.6
2	Reliability	1.0
3	Spacer compatibility	1.0
4	Testing volume	0.4
5	Realisticity	0.6

As shown in Table 4.1, manufacturability is given a weighting score of 0.6 - this is due to time restrictions. It is important that the test rig is not too challenging to make, to ensure that the product will be finished within the time limit. Reliability and spacer compatibility is crucial to provide adequate results, and is therefore given the score 1.0. It is specified in the task description that the rig should be compatible with both liquid and mechanical spacers. Concepts who only work with one of the two spacers will get a lower score than the ones capable of using both. Testing volume is important to a small degree. Flow rate is specified to be low, which means that required testing volume also is low, and thus it has been given a score of 0.4. The final criterion is realisticity, and has been given the score 0.6. It is limited how realistic the test rig is capable of being, because of the fact that it is a small-scale simulation of a pipe line. Under actual conditions, spacers will be injected in one end of pipe and extracted in the other end, and this is not possible to achieve here. It is still important that the rig resembles a real life scenario, and is therefore given the weighting score 0.6.

4.2 Scoring

In this section, the scores of each concept will be presented along with the total scores after using the Concept Selection Scoring Method. The scores are presented in Table 4.2-4.6.

4.2.1 Concept 1, "Bicycle Wheel"

Concept 1 receives a score of 4 on manufacturability. The concept is considered to be relatively easy to build, with the exception of the need of magnetizing the spacers. It also receives a score of 4 on reliability. There are few sources of error, but due to the fact that it is dependent on relative motion between pipe and fluid, the concept does not receive top score. The concept is given a score of 2 on spacer compatibility, because it only works with mechanical spacers. It receives a score of 3 regarding testing volume because it is limiting how big a wheel can be built without encountering problems such as stiffness of the wheel and space around it. Due to the concept's dependence on relative motion, it is seen as not realistic, and only receives a score of 2.

Table 4.2: Concept 1: rating, d$_n$, of the nth criteria.

Criterion	Rating
Manufacturability	4
Reliability	4
Spacer compatibility	2
Testing volume	3
Realisticity	2

4.2.2 Concept 2, "Rotating Staff"

Concept 2 is considered to be the most unproblematic concept to build, and therefore is given a score of 5 when taking manufacturability into consideration. This concept is seen as unreliable due to variations in fluid motion and uncertainties tied to use of liquid spacer. It will therefore receive a score of 2 regarding reliability. This concept is similar to concept 1 when comparing spacer compatibility because it only works with mechanical spacers, and is therefore given the same score of 2. This is the only concept which is not a closed loop, which gives the concept limitations regarding testing volume, and thus receiving a score of 2. These limitations also contributes to lack of realisticity for the concept, which is reflected in a score of 1.

Table 4.3: Concept 2: rating, d$_n$, of the nth criteria.

Criterion	Rating
Manufacturability	5
Reliability	2
Spacer compatibility	2
Testing volume	2
Realisticity	1

4.2.3 Concept 3, "Circular Loop, Version 1"

With exception of the bypass, the concept is a closed loop with a pump attached, and is consequently considered a score of 4 regarding manufacturability. The concept consists of few sources of error, and should produce consistent results. It receives a score of 4, because the use of the bypass may contribute to some problems. The pump attached to the pipe reduces the spacer compatibility, considering that mechanical spacers can not go through a pump. It is therefore given a score of 3. This concept is a circular rig which therefore allows for higher test volumes compared to concept 2, since a circular rig will occupy less space, even when containing a longer pipe distance. The score given is 4. The fact that this is a circular rig will also result in a more realistic setup, since the fluid flows through the pipe in a similar way to a real life scenario. This is reflected in the score, which is 4.

Table 4.4: Concept 3: rating, d$_n$, of the nth criteria.

Criterion	Rating
Manufacturability	4
Reliability	4
Spacer compatibility	3
Testing volume	4
Realisticity	4

4.2.4 Concept 4, "Circular Loop, Version 2"

This concept is similar to concept 3, which is reflected in the similar scores. Manufacturability is the only score that differs, because of the fact that the bypass used for injection of spacers contains multiple valves and additional sources of error. The score given is 2 because of the added complexity. The rest of the scores remain with the same values as the previous concept.

Table 4.5: Concept 4: rating, d$_n$, of the nth criteria.

Criterion	**Rating**
Manufacturability	2
Reliability	4
Spacer compatibility	3
Testing volume	4
Realisticity	4

4.2.5 Concept 5, "Circular Loop, Version 3"

This concept is also similar to both concept 3 and concept 4, which again is reflected in the scores. Once again manufacturability is different. The concept is considered to be a score of 3. The strainers used for the bypasses is seen as a more difficult solution than in concept 3, but still simpler than the bypass solution in concept 4. The bypass solution used in this concept allows for the use of both mechanical and liquid spacers, which means that the score when considering spacer compatibility is 5.

Table 4.6: Concept 5: rating, d$_n$, of the nth criteria.

Criterion	**Rating**
Manufacturability	3
Reliability	4
Spacer compatibility	5
Testing volume	4
Realisticity	4

4.3 Total Scores

The ratings of each criteria for every concept is listed in Table 4.2-4.6. In Table 4.7, the final scores are listed, when taking the weighting into account.

Table 4.7: Total score of all concepts.

Criteria	**Weighting**	**No. 1**	**No. 2**	**No. 3**	**No. 4**	**No. 5**
Manufacturability	0.6	4	5	4	2	3
Reliability	1.0	4	2	4	4	4
Spacer compatibility	1.0	2	2	3	3	5
Testing volume	0.4	3	2	4	4	4
Realisticity	0.6	2	1	4	4	4
Total score		10.8	8.4	13.4	12.2	14.8

As shown in Table 4.7, concept 5 is the best candidate, and will therefore be the concept of choosing. The scores are calculated by using Equation 2.1, and are an objective evaluation, based on how the different qualities of each concepts are estimated to work under operating conditions.

Table 4.8: Concepts listed from least suited to best suited.

	Concept
Worst	Concept 2, "Rotating Staff"
|	Concept 1, "Bicycle Wheel"
|	Concept 4, "Circular Loop, Version 2"
|	Concept 3, "Circular Loop, Version 1"
Best	Concept 5, "Circular Loop, Version 3"

The main reason to why concept 5 comes out with the highest total score is because of the high scores regarding both spacer compatibility and reliability. Those are the two most important criteria with a weighting score equal to 1.0, which greatly affects the final score of the concept. This is also the reason to why the other concepts are estimated to be less appropriate, due to the lower score regarding spacer compatibility and reliability. Concept 5 is the best candidate, every criteria taken into consideration. Not only because of the two criteria mentioned above, but because of strong scores among the rest of the criteria as well.

Chapter 5

Discussion

5.1 Adjustments and Modifications

During the process of developing the different concept suggestions, a change of preliminary conditions occurred. The loop was initially expected to have the option of seamless spacer injection. This however, changed due to fact that it was no longer needed for the master students to have a seamless injection of spacers. In light of this, a re-evaluation of the so far best concept was made.

In the process of creating a product, or in this case a test loop, it is normally needed to adjust and modify parts and/or sections of said loop to overcome problems that are discovered during production. As shown in the section regarding results, concept 5 was the concept of highest interest. Although concept 5 was chosen, it may still not be perfect, and improvements can always be made depending on needs. After getting a wider understanding on how the system is going to work, as well as input from an engineer at NTNU, a better solution was introduced to the loop. To enable smoother flow and a more reliable system, the bypass with strainers and pumps was replaced with a single pump. The tube inside of a peristaltic pump has got an ID large enough for an appropriately sized mechanical spacer to pass through it. This unlocked the possibility of reducing both complexity of the system, as well as making it more reliable, easier to build, and fundamentally better.

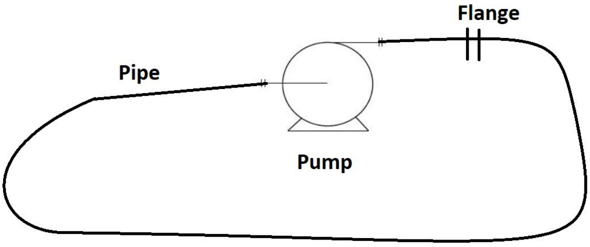


Figure 5.1: Displaying the modified set up.

Due to the changes done to concept 5, a description of how the modified loop is going to work is needed. As mentioned above, the strainers and pumps are replaced by one peristaltic pump. This reduces the quantity of parts needed, which affect both cost and time needed to put the rig together. From here on out the modified version of concept 5 will be called concept 6, for clarification purposes.

5.2 Concept 6

5.2.1 Description

Concept 6 consists of a transparent tube, a peristaltic pump, and a flange connection. The system does not include a spacer injection site, but offers a reliable and steady flow of fluids and spacers. The loop is closed, and circular motion of the test medium allows for infinite testing distances. Before the test starts, wanted test fluids are loaded into the tube, as well as spacers to separate the different fluids. After both spacers and fluids are loaded and ready inside the tube, the flange connection is sealed and the test is ready to start. Next, the peristaltic pump is started, and the test is hereby running. After a sufficient time period, the pump is shut down and the test is complete. During testing, the transparency of the tube allows for continuous observation of fluids. This is an important aspect of the test, and helps when judging if the spacer is working properly.

5.2.2 Scoring

To get a better picture of which qualities that improved as a result of the modifications done to concept 5, concept 6 is compared to the predecessor - concept 5. Below is a table displaying these differences, Table 5.1. Green numbers indicates a better score, and red color is used to highlight the weighting which is the same for both concepts.

Table 5.1: Comparison between concept 5 and concept 6.

		Concept 5	**Concept 6**
Criterion	**Weighting**	**Score**	**Score**
Manufacturability	0.6	3	5
Reliability	1	4	5
Spacer-compatibility	1	5	5
Testing volume	0.4	4	4
Realisticity	0.6	4	4
Total score		14.8	17

The reason to why concept 6 is assigned a better score on both manufacturability and reliability, is due to the removal of bypass pipes. The bypass introduces a level of uncertainty to the loop, in the sense that the fluid has got two separate pipes to follow, and synchronizing these paths can be a challenging effort. Figure 5.2 shows a possible bypass solution.

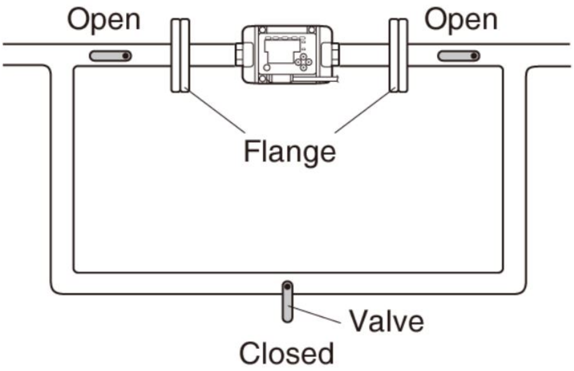


Figure 5.2: Displaying a bypass. (KEYENCE CORPORATION, 2019)

For fine-tuned computer systems, it is possible to achieve seamless usage of a bypass, shown in Figure 5.2. But this test rig is to be operated by hand, and it can therefore be difficult to use the bypass without any fluids mixing. The new solution in concept 6 eliminates this issue completely, thus increasing the reliability score from 4 to 5. Manufacturability also gets an increase of score, due to the fact that it is easier to build with the new solution. Concept 5 included a system of strainers and pumps. The strainers had to manually be applied to each end of the bypass and sealed tight so that it kept its integrity through many runs of the test loop. Concept 5 also includes more parts in general, which is cause for more potential sources of error. These factors taken into consideration made concept 6 get a total score of 17, 2.2 better than concept 5.

Table 5.2: Final scores of every concept, including concept 6.

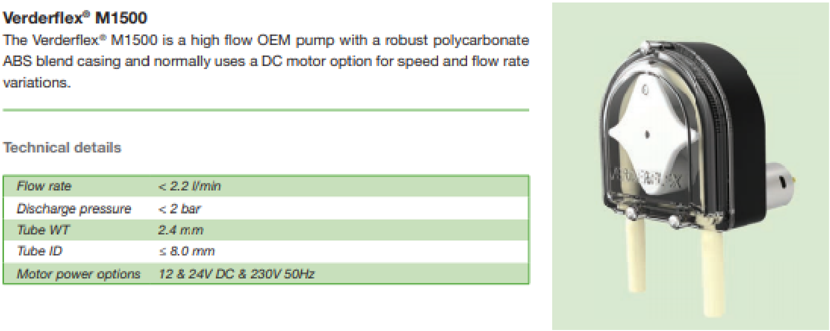
Concept	Score
No.1	10.8
No.2	10.4
No.3	13.4
No.4	12.2
No.5	14.8
No.6	**17**

With a total score of 17, concept 6 is by far the most qualified concept, and is the final solution that is to be built. Final scores for all concepts, including concept 6 is shown in Table 5.2.

5.3 Selection of Parts and Components

As shown in Table 5.2, concept 6 is considered to be the best candidate. The components needed for this concept was one peristaltic pump, a tube, and a flange. The most essential component for this concept was the pipe type. A requirement from the master students, as shown in Table 1.1, who will be using the test rig for experiments, was that the tube needed to be transparent. The reason for this was that a transparent tube would allow for constant surveillance of both fluids and spacers during experiments.

The next component to decide was to choose a correct pump for the test rig. There is no external pressure acting on the fluids inside the tube. A pump is needed to start and maintain a constant fluid velocity. Due to the multiphase flow in the tube, it is of great importance to choose a pump with a low shear. This is to keep the liquid spacer intact while passing through the pump. If the shear is too high, there is a risk of the liquid spacer not working optimally, and fluids might mix. In this case low shear is defined as not causing large droplets to be degraded into smaller ones (Flanigan et al., 1988). When choosing the pump, the choice was a peristaltic pump. A peristaltic pump is a positive displacement pump using a rotary displacement element. The rotary displacement element applies pressure to a tube locked in place inside the pump. Due to the fact that the fluids always is inside a tube, which then is applied pressure, it was concluded that this was a good choice regarding low shear.



Verderflex® M1500

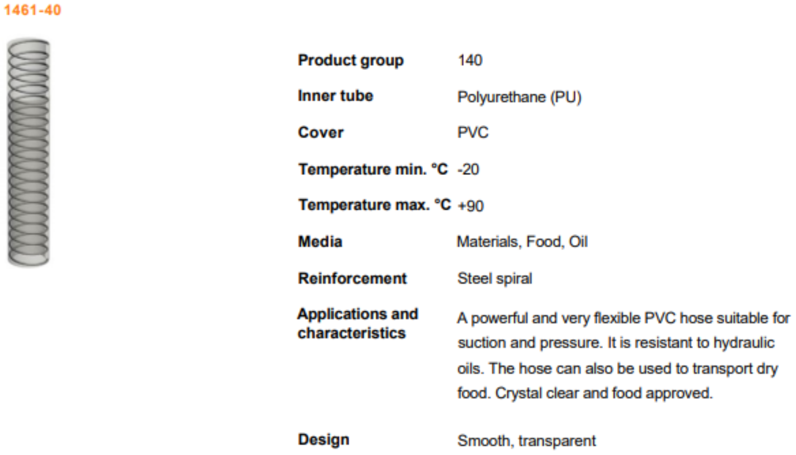
The Verderflex® M1500 is a high flow OEM pump with a robust polycarbonate ABS blend casing and normally uses a DC motor option for speed and flow rate variations.

Technical details

Flow rate	*< 2.2 l/min*
Discharge pressure	*< 2 bar*
Tube WT	*2.4 mm*
Tube ID	*≤ 8.0 mm*
Motor power options	*12 & 24V DC & 230V 50Hz*

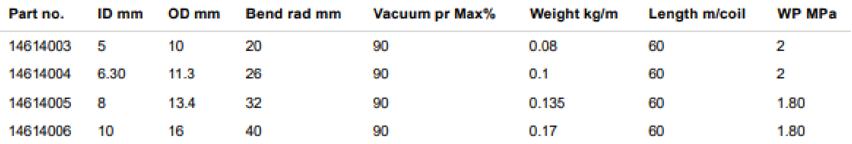
Figure 5.3: Product overview, pump. (Verder International B.V., 2019)

As shown in Figure 5.3, the maximum tube ID possible inside the pump is 8.0 mm. For the solution mentioned in the previous section to function, the main pipeline also needs to be a maximum of 8.0 mm ID. Also shown in Figure 5.3, is the flow rate the pump will be able to provide. The maximum flow rate the pump will provide, according to the company's own product overview catalog, is 2.2 l/min (Verder International B.V., 2019). As shown in Table 1.1, a requirement for the test rig was a flow rate of 1-2 l/min. According to information from the manufacturer, this will be possible with the selected pump.



1461-40

Product group	140
Inner tube	Polyurethane (PU)
Cover	PVC
Temperature min. °C	-20
Temperature max. °C	+90
Media	Materials, Food, Oil
Reinforcement	Steel spiral
Applications and characteristics	A powerful and very flexible PVC hose suitable for suction and pressure. It is resistant to hydraulic oils. The hose can also be used to transport dry food. Crystal clear and food approved.
Design	Smooth, transparent



Part no.	ID mm	OD mm	Bend rad mm	Vacuum pr Max%	Weight kg/m	Length m/coil	WP MPa
14614003	5	10	20	90	0.08	60	2
14614004	6.30	11.3	26	90	0.1	60	2
14614005	8	13.4	32	90	0.135	60	1.80
14614006	10	16	40	90	0.17	60	1.80

Figure 5.4: Product overview, tube. (HYDROSCAND, 2019)

This was taken into consideration when selecting the correct tube as well. As shown in Figure 5.4, this tube was available with an ID of 8.0 mm.

This tube also became a natural choice because of its additional properties. The tube is transparent, which is necessary when conducting the experiments. This allows for visual surveillance at all times. Visual surveillance is important to ensure the experiments run smoothly.

The tubes other properties are also fitting for this assignment. Because of the fact that the experiment is running at room temperature, the tubes temperature limits are well within range.

5.4 Assembly

The flange connection is installed onto the test rig in order to have the option of opening and closing the loop. The reason for this is to easily fill, empty, and refill the tube with production chemicals and spacers. The filling and emptying process is performed manually. In order to do this as effective as possible, it is necessary to build the loop with an appropriate length. To allow fluids and spacers either to fill or empty the tube, the tube needs an inclination. This is needed in order to fill the pipe with as little air as possible, due to the suction of the peristaltic pump. As mentioned earlier in this thesis, it is limited space available at the workshop at SINTEFs Petrotechnical center. The length of the tube is therefore decided by the space available while still being able to keep the tube at an inclination while the flange is in an open position. This length was decided to be a maximum of 100 meter. Furthermore, the tube is connected to the pump and strapped along bars of a structure in the workshop, shown in Figure 5.5. In order to get the best possible results it is important that the tube is fixed as tight as possible to the bars. If not, the movement of fluids inside the tube can loosen the straps. For the purpose of achieving inclination, second, third and fourth floor was used to strap down the 100 meter long tube.

Figure 5.5: Shows the structure the tube is fixed to.

Table 5.3: Specifications for the final test rig.

Total length of tube	100 m
Available volume inside the tube	Approximately 5 L

5.5 Quality Control

The final part of the practical work in this thesis is to review the final product. For this, a two-step test is created. Water is determined to be used as test fluid in the first test. The reason for this, is that this review's main purpose is to test if the pump, inlet, outlet, and flange is working properly. The entire system is then filled up with water and sealed by tightening the flange. Next, the peristaltic pump is started which sets the water in motion, and thus starting the test. During this particular test, both tube and connections along the tube will be carefully examined for leaks and other signs of failure. Due to the transparency of the tube, it is also possible to perform visual inspection of the flow inside the tube during the test. This is done to check as many parameters as possible that later is going to affect the test rig's performance.

Figure 5.6: Displaying a setup configuration of the tests.

In the second test, a combination of liquid spacers and water is used. A liquid spacer is mixed in the lab using Xanthan gum, which is a powder that increases the viscosity of a fluid drastically. Xanthan gum is mixed with water to create the liquid spacer. Two different solutions are mixed, one with 1 wt% Xanthan gum and the other with 0.5 wt%. The reason to why two solutions are mixed, is to check how the pump responds to different levels of spacer viscosity. In this test, water is first pumped into the tube and after that, a spacer with 0.5 wt% Xanthan gum. Then, water with a blue dye is pumped into the tube followed by the more viscous 1 wt% spacer solution. Blue dye is used to distinguish between different fluids and spacers, shown in Figure 5.7. The test rig is filled up with the spacers and water, and set to run for a short period of time. During the test, the entire rig is inspected and checked for signs of failure.

Figure 5.7: Showing the effect of water with a blue dye.

A small test with a mechanical spacer was conducted before the rig got assembled. The test consisted of 0,5 meter tube through the pump, and reviled that the current tube is too rough on the inside for a mechanical spacer to pass through. To enable usage of mechanical spacers, a smoother tube is needed.

5.5.1 Results of Quality Control

During both first and second test, the pump was able to uphold a steady flow with no signs of failure. The transparency of the tube worked as planned, and enabled surveillance during the test. Some air was mixed into the loop when the spacer was injected into the tube, which resulted in a gathering of air some locations inside the tube. This can be avoided by being more cautious when injecting both spacers and testing fluid as well as letting air bubbles in the Xanthan gum settle in a vacuum chamber before injection.

Chapter 6

Conclusion

In this chapter, this thesis will be concluded. Furthermore, recommendations for further work will be outlined.

6.1 Conclusion

The background for this thesis was to explore the possibilities of removing lines of production chemicals from the umbilical. This would reduce the total price of the umbilical. To further explore these possibilities, the aim for this thesis was to construct a test rig to simulate a subsea pipeline.

A set of concepts were first considered, to eventually become the final test rig. The concepts were each rated on five criteria, which were considered to be essential for the final product. By using the Concept Scoring Selection Method, a final concept achieved the highest score, and thus became the concept to build.

When ordering the parts to the chosen concept, a new solution for the test rig was developed. The new concept simplified the the test rig, by reducing the number of parts needed. It most likely also contributed to more reliable results.

The test rig constructed in this thesis is tested with both water and liquid spacers. It is also conducted a small test with a mechanical spacer before the test rig got assembled. Water and liquid spacers worked properly with no signs of failing, but the mechanical spacers is not able to go through the rig with the current tube - it is simply not smooth enough on the inside.

6.2 Recommendations for Further Work

The test rig built in this thesis is simplified in comparison to a subsea pipeline. Recommendations for further work would therefore be to make the test rig more realistic than the rig constructed in this thesis. It would be of advantage to make the rig on a larger scale, most importantly to examine if the spacers would be as effective, despite larger volumes to divide.

A way to increase the realisticity of the results of the testing, would be to include more factors to consider for the test rig which would be of importance subsea. Factors such as temperature and pressure could influence the transport of production chemicals subsea, and would therefore increase realisticity for the test rig when included.

To enable mechanical spacers to flow through the tube, it is recommended to use a tube with a smoother internal surface. Removal of air bubbles in the liquid spacer is also recommended to get less air in the rig during testing. This can be done by placing the liquid spacer in a vacuum chamber before use.

In order to increase the reliability of the experiments, further work can be done regarding the emptying- and filling processes. For the test rig constructed in this thesis, these processes were performed manually. To increase accuracy and efficiency of the experiments, which contributes to higher reliability, automated refilling- and emptying systems is recommended for further work.

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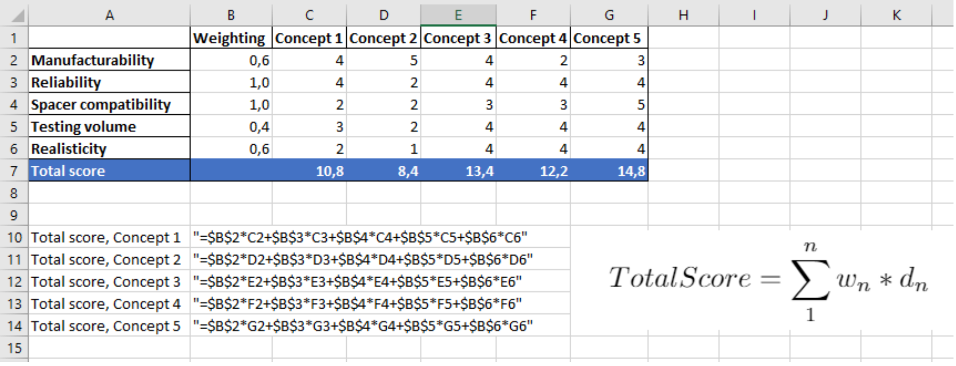
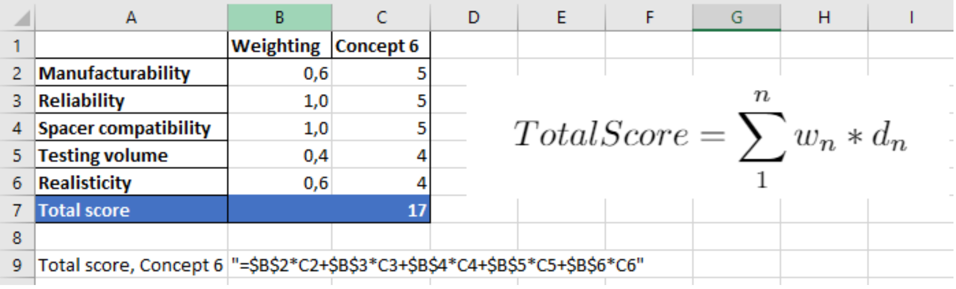
Appendix



	A	B	C	D	E	F	G
1		Weighting	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
2	Manufacturability	0,6	4	5	4	2	3
3	Reliability	1,0	4	2	4	4	4
4	Spacer compatibility	1,0	2	2	3	3	5
5	Testing volume	0,4	3	2	4	4	4
6	Realisticity	0,6	2	1	4	4	4
7	Total score		10,8	8,4	13,4	12,2	14,8
8							
9							
10	Total score, Concept 1	"=\$B\$2*C2+\$B\$3*C3+\$B\$4*C4+\$B\$5*C5+\$B\$6*C6"					
11	Total score, Concept 2	"=\$B\$2*D2+\$B\$3*D3+\$B\$4*D4+\$B\$5*D5+\$B\$6*D6"					
12	Total score, Concept 3	"=\$B\$2*E2+\$B\$3*E3+\$B\$4*E4+\$B\$5*E5+\$B\$6*E6"					
13	Total score, Concept 4	"=\$B\$2*F2+\$B\$3*F3+\$B\$4*F4+\$B\$5*F5+\$B\$6*F6"					
14	Total score, Concept 5	"=\$B\$2*G2+\$B\$3*G3+\$B\$4*G4+\$B\$5*G5+\$B\$6*G6"					
15							

$$TotalScore = \sum_{1}^{n} w_n * d_n$$

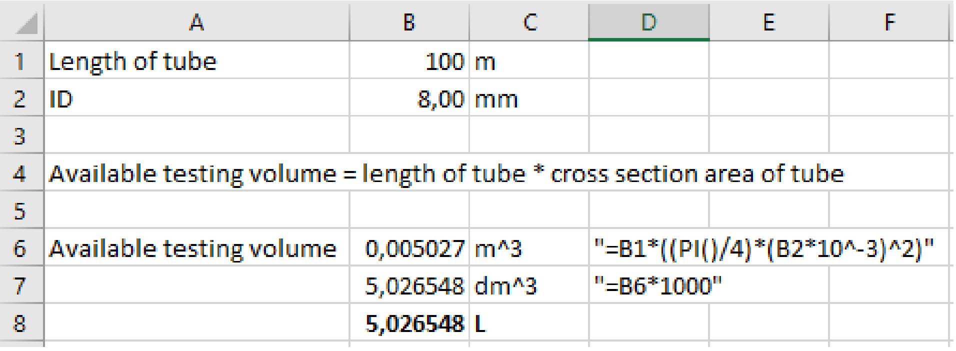
Figure 6.1: Calculations made using the Concept Scoring Selection Method, Equation 2.1. Concepts 1-5.



	A	B	C
1		Weighting	Concept 6
2	Manufacturability	0,6	5
3	Reliability	1,0	5
4	Spacer compatibility	1,0	5
5	Testing volume	0,4	4
6	Realisticity	0,6	4
7	Total score		17
8			
9	Total score, Concept 6	"=\$B\$2*C2+\$B\$3*C3+\$B\$4*C4+\$B\$5*C5+\$B\$6*C6"	

$$TotalScore = \sum_{1}^{n} w_n * d_n$$

Figure 6.2: Calculations made using the Concept Scoring Selection Method, Equation 2.1. Concept 6.



	A	B	C	D	E	F
1	Length of tube	100	m			
2	ID	8,00	mm			
3						
4	Available testing volume = length of tube * cross section area of tube					
5						
6	Available testing volume	0,005027	m^3	"=B1*((PI()/4)*(B2*10^-3)^2)"		
7		5,026548	dm^3	"=B6*1000"		
8		**5,026548**	**L**			

Figure 6.3: Calculations made to determine available testing volume inside the tube.

Construction a Flow Loop

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Abstract

The purpose of this thesis is to construct a test rig, designed to further explore the possibilities of subsea chemical injection through a single pipeline. The test rig is constructed at the workshop at Petrotechnical center. It is concluded that the best solution is a closed loop, which in theory is able to simulate infinite pipeline distances. The test rig is compatible with both mechanical and liquid spacers, which is necessary to keep fluids from mixing when transporting different fluids through a single pipe. Furthermore, a set of parameters given by two master students, is used as base for the construction. A variety of different approaches regarding type of test rig is discussed.

Introduction

The petroleum industry is in constant need for new and better equipment, as well as better procedures for extraction of oil and gas. Every piece of equipment and every meter of a pipe counts when it comes to saving money. But saving money shall not go at the expense of the safety of the ones working on a platform. It is therefore an important task to reduce the cost of subsea operations without negatively affecting the probability of an accident occurring. To ensure safety of the crew as well as optimal production, the usage of production chemicals has been implemented into the petroleum industry. Currently these chemicals are pumped to distribution tanks and/or manifolds located at the seabed through an umbilical. The umbilical consists of a number of different wires and smaller pipes to feed hydraulics, electricity and production chemicals to the subsea production (Bai, Y. and Bai, Q. 2010). The electrical, hydraulic and chemical lines are wrapped up in a protective coating to prevent unwanted fluids and particles to enter the chord. All this taken into consideration adds up to a significant price tag on the umbilical, and it is therefore wanted to unlock the possibility of making it cheaper. This is especially important at smaller fields placed far away from existing infrastructure, cause then, several kilometers of umbilical is needed. One way of reducing the price of an umbilical is to remove the lines of production chemicals. But then, a different and more effective way of transporting these chemicals has to be brought into use. In this thesis it is assumed that the production chemicals will be stored in large tanks subsea and refilled upon depletion. (Peyrony and Beaudonnet, 2014) It is requested that refilling will happen by a single pipeline where the chemicals are pumped subsea in quick succession and separated in the pipe only by either a mechanical or a liquid spacer. In order to test if this is a possible solution, a test rig is needed, which will be the issue at hand in this thesis - constructing a test rig.

Goal of the thesis

- Constructing a test rig for laboratory testing of single pipe, batch based transport of production chemicals.

The scope of this thesis is the establishment of a test rig best suited for methodic testing of transport of production chemicals. The test rig is a small-scale simulation of a pipeline, built to provide necessary information to determine if single pipe distribution of chemicals is a viable solution. Chemicals will be sent sequentially in a single pipe and separated by either mechanical or liquid spacers. The rig must be able to provide consistent results regarding test medium and spacers.

For the goal of this thesis to be met, a theoretical research is first conducted. When adequate information of the the problem at hand is gathered, different solutions are discussed in order to end up with the best possible result.

Approach

For the purpose of ending up with a good result, several options had to be considered. The different concepts and proposals for a test rig was brought forth through a process of thinking, meetings and conversations. For every concept it started with a simple sketch and an idea, and if the idea showed promise, it was taken to the next step, which was a meeting with the supervisors. If the concept had not yet been discarded in an early stage, it was brought into the thesis in a more detailed fashion. Every concept was then listed and evaluated against the same criteria. The criteria chosen is listed in the section below.

Idea –> **Sketch** –> **Presentation of concept** –> **Further research**

Figure 1 shows a flowchart displaying the process of finding different concepts.

Criteria

Manufacturability is chosen as a criteria to evaluate how difficult it is to build the rig.
Reliability is of great importance to the rig. It may need to be running experiments for an extended period of time without failure. This is needed to achieve accurate results,hence the importance of reliability as a criterion.
It is specified in the design requirements that it is expected of the rig to be compatible with both liquid and mechanical spacers. The concepts will therefore be evaluated against spacer compatibility.
When conducting experiments to replace existing solutions in the industry, it is important that the experiment is realistic.Realisticity is therefore brought in as a criterion to determine whether or not the rig resembles a real life scenario.
A high amount of test volume will result in a higher likelihood of good result than a low amount of test volume. To simulate larger volumes, the rig can also have seamless replacement of chemicals and spacers.The criteria is weighted from 0 to 1.

Theory

To select the correct concept, a method called Concept Scoring Selection Method was used. The method uses a scoring matrix to evaluate concept alternatives. Criteria are chosen subjectively based on design requirements. The criteria are assigned a weighting, dependant on how important the criterion is to the final product. A percentage is normally used to assign the weight. Concepts are given a rating from 1 to 5, where 1 is low and 5 is high, on each of the criteria. Once all the concepts are rated, a total score for each concept is calculated using the following formula:

$$TotalScore = \sum_{1}^{n} w_n * d_n \tag{1}$$

Where n is the count of criteria, w_n is the weight of nth criteria, and d_n is the rating of the nth criteria.

The concept with the highest total score is assumed to be the best concept, given the criteria and their weighting.

Criteria wheighting

In order to decide which of the concepts presented that was going to be constructed, the Concept Scoring Selection Method was brought into practice. Before the scoring method could be used, the score weighting had to be determined. The weighting concerning each criterion was decided based on the parameters and assumptions that had been made for this particular thesis. The weighting score is a number between 0 and 1, where 0 means that the criterion is non important, while on the other hand, 1 indicates that the criterion is of great importance.

Table 1 showing the different criteria wheightings

No.	Criterion	Weighting
1	Manufacturability	0.6
2	Reliability	1.0
3	Spacer compatibility	1.0
4	Testing volume	0.4
5	Realisticity	0.6

Results

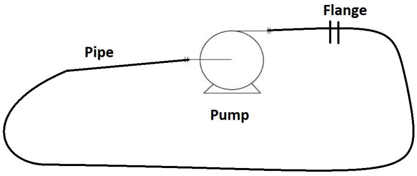

Figure 2 shows the best concept and also the concept who was built

Conclusion

The background for this thesis was to further explore the possibilities of removing lines of production chemicals from the umbilical. This would reduce the total price of the umbilical. To further explore these possibilities, the aim for this thesis was to construct a test rig to simulate a subsea pipeline.A set of concepts were first considered, to eventually become the final test rig. The concepts were each rated on five criteria, which were concidered to be essential for the final product. By using the Concept Scoring Selection Method, a final concept achieved the highest score, and thus became the concept to build.When ordering the parts to the chosen concept, a new solution for the test rig was developed. The new concept simplified the the test rig, by reducing the number of parts needed. It most likely also contributed to more reliable results.

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2. Peyrony and Beaudonnet, 2014

ID	31206	**Status**	**Dato**
Risikoområde	Risikovurdering: Helse, miljø og sikkerhet (HMS)	Opprettet	07.02.2019
Opprettet av	Herman Johan Emil Brodd	Vurdering startet	07.02.2019
Ansvarlig	Herman Johan Emil Brodd	Tiltak besluttet	
		Avsluttet	

Risikovurdering:

Bachelor

Gyldig i perioden:
2/7/2019 - 5/20/2019

Sted:
SINTEF, Petroleumteknisk senter

Mål / hensikt
Eksperimentelt arbeid til bacheloroppgave.

Bakgrunn
Lage en strømningssløyfe som skal simulere injisering av produksjonskjemikalier, separert av spacere, til pipelines.

Beskrivelse og avgrensninger
Valg av konsept enda ikke klart, men mulig vi vil være avhengig av ulikt dynamisk utstyr som f.eks. pumpe og ventiler.

Forutsetninger, antakelser og forenklinger
Forenklinger: arbeider sannsynligvis ikke med reelle produksjonskjemikalier. Vil arbeide på et trykknivå som er lavere enn en reell situasjon.

Vedlegg
[Ingen registreringer]

Referanser
[Ingen registreringer]