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Design of experimental loop to demonstrate pigging activity

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Marina Makarova

Master's thesis in Industrial Engineering, May 2017

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The main purpose of this thesis is to study a pigging activity and make a detail design of experimental loop for UiT Campus in Narvik. Thesis include extensive literature study for pig plugs, GPS routing, corrosion and roughness measuring. The overview of safety requirements also have been done. Design process follows the systematic thinking approach described in the Nigel Cross book “Engineering Design methods”. For each part list of materials and technical drawings were done. Valves and pump also was chosen. In the end suggestions about connection between pig plug and PC were given, the desired interface layout is presented.</td></tr>
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Foreword

This report is a part of graduated work at UiT Campus Narvik in the Master program in Industrial Engineering. This assignment was given by Faculty of Engineering Science and Technology in UiT.

Period of the working time is 26 weeks; 9 of them were given for part I and 18 weeks for part II. This report include 49 pages and 3 appendices.

Acknowledgments

First, I would like to express my sincere gratitude to my advisor Geanette Polanco for the continuous support of my master thesis, for her motivation, patience, and tremendous knowledge. I could not have imagined having a better advisor and mentor for my work. Her guidance helped me in all the time of working on this thesis.

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Narvik, 01.05.2017

Marina Makarova

Abstract

Our world is continuously developing by new generation of engineers, artists, politicians, travelers and this list can be continued. They will research, improve and design new reality for the future. One of our missions is to help them by bringing better understanding of existing technologies. This is the goal of my thesis: to create an experimental loop to demonstrate pigging activity in the pipelines.

This thesis includes two parts: literature study and design process. First part covers the introduction about pig plugs and pigging activity itself. It contains description of different types of plugs, their material, functionality and classification. Requirements for piggable pipelines are also listed in the text. Further information covers explanation of pigging units, launching and receiving stations. Theory about energy considerations for the system also given in the part I. Next topic covered is tracking pig position along the pipeline. To get an understanding about this process, the investigation about GPS principles have been done.

Collection information about inner surface of the pipe is next point of the thesis. Extended description of different types of corrosion and method of its detection is given in the text. The research about roughness measuring also was performed.

Part II of the thesis covers the design process of the experimental loop. This process includes clarification of objectives, setting requirements, generation alternatives, 3D modeling and listing all required materials for the pipeline components. Moreover, choice of pump and valves also have been done and suggested models was given. In the end of work, suggestion about plug connection with PC and desired interface layout is presented.

Abbreviations

AFM - Atomic Force Microscope

AISI - American Iron and Steel Institute

DIN - German Institute for Standardization (*germ*. Deutsches Institut für Normung)

GLONASS - Global Navigation Satellite System, Russian GPS

GPS – Global Positioning System

HSE – Health and safety executive

ID – Inner diameter

MCU – Microcontroller unit

NAVSTAR - Navigation System Using Timing and Ranging, American GPS

NORSOK - Norwegian shelf's competitive position (*norwegian*, Norsk Sokkels Konkurranseposisjon)

OPS – One Pig System

PIG – Pipeline Intervention Gadget

STM - Scanning Tunneling Microscopy

TPS – Two Pig System

1 Introduction

Pipelines represent a considerable investment for the operators and can often be strategic assets to countries and governments. They are generally accepted as being the most efficient method of transporting fluids across distances. In order to protect these valuable investments, maintenance must be done and pigging is one of such maintenance tool. Pig plugs can be used to remove debris, to fill the pipeline with water, to dewater the line after test, to remove liquid hold-up, clean wax, apply corrosion inhibitors, carry ultrasonic or magnetic sensors to incept the pipes, etc. Understanding and testing the pigs and pigging activity in the pipes has a significant value for different industries.

One of the ways to improve understanding of the pigging activity by students is to give an laboratories exercises in university. The main aim of this thesis is to design a test stand for University In Tromso Campus in Narvik. This school have a study program oriented for oil and gas industry and the experience with pig plugs will be very valuable for students in this program.

This thesis will cover the literature overview and the design process for experimental loop. Main aspect is to design a test stand, which will be possible to manufacture using facilities in UiT workshop and by use of as many purchased parts as possible. Assembly of the loop also should be possible to perform in the workshop.

2 Background

The selected pipeline maintenance topic is focused on the activity called pigging. The background required to cover sufficiently the needed aspects to design a pipe loop used to demonstrate the pigging activity is first presented in a graphical way in Figure 1. This review starts with the definition and description of the pig plug and pig units, which will be installed in a pipe system with the proper energy considerations required. Following a brief of the requirements and constrains imposed by the corresponding standards and regulation is given, and finally the review of the instrumentation required to collect information about location, corrosion and internal pipe roughness. All aspects are interconnected and all of them are equally important to achieve a functional design.

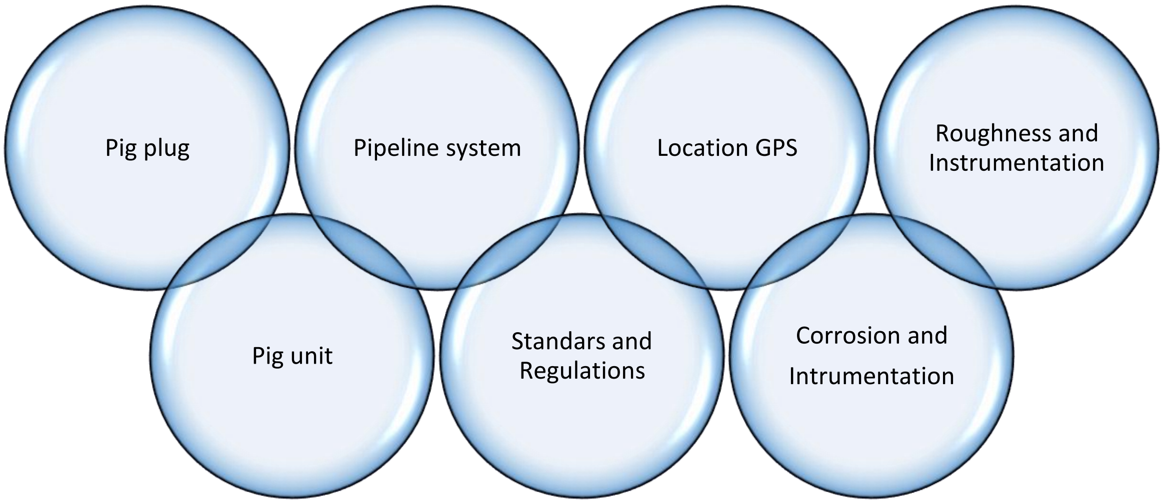


Figure 1 - Schematic representation of required background of aspects to understand pigging activity.

Part 1

2.1 Pigs and pigging activity

There are different versions how the plug "pig" got its name. First theory that one of pipe liners was standing next to pipe when the device went past him inside the pipe and he heard a noise similar to a pig squealing. The second theory referred to abbreviation from Pipeline Intervention Gadget (PIG) (1). Regardless the name, pig plugs are currently one of the most common used devices for pipes service in different industries (1).

Pigging activity can be defined as propulsion of a mobile plug pig through a pipe. Inside the pipe this plug can execute certain activities. The beginning of pigs' application can be referred to oil and gas industry from earlier 70^{th} (2). By time pigs have been developed and their functions were expanded from cleaning and sealing to control, inspection and quality check. They can be fluid-driven or self-driven (2). Based on the task, which pig devices are design for, they can be divided into three following categories (3):

1) *Utility pigs*. Utility pig are design to perform two main roles in pipes: clean and seal. Cleaning function include the removing solid or semi-solid debris, deposits or wax from the pipes. Sealing pigs provide a good seal to sweep liquids from the line, or to separate different products inside the pipes.
2) *In-line tools for inspection* or smart pigs. This type of plugs are used to provide information about condition of the pipe, rate and location of the problem. Smart pigs are designed to gather following information: measure of geometry/diameter, pipeline profile, monitoring of the curvature, metal-loss, corrosion detection, cracks and leaks detection, measurements of bends and wax deposition, product sampling and mapping. Modern smart pigs are equipped with variety of sensors, optical devices, etc.
3) *Gel pigs*. Gel pigs are used together with utility pigs to improve dewatering, drying and cleaning functions (3).

2.2 Types of PIG plugs

Pig plug exist in different designs, types, sizes, materials and shapes. There is a common classification of pig plugs:

1) Foam pigs. They are commonly used for cleaning, drying, batching, product removal operations. Foam plugs are versatile, lightweight and flexible. Their main advantage is the possibility to negotiate uncommon piping, valves and fittings. Foam pigs exist in common configurations:

bare, criss-cross, wire-brush, silicon carbide and plastic bristle (4). Most common design of foam pig plug are shown on Figure 2a.

2) Solid cast pigs. Solid cast pig design provides flexibility, easy handling, toughness and excellent sealing capabilities of cups and discs. Solid cast pigs are used for product removal, hydrostatic testing, displacement, batching and other routine operations. Additional attached brushes and scrubs make this type of pig plugs available for usage in pipeline's cleaning. Material properties allow pigs negotiate tight-radius bends and varying internal diameters (ID) of the pipe with same nominal size (4). There are available various configurations, including cup-type, disc-type, sphere, and complex cup-disc-type. Figure 2b shows different designs of solid cast pigs.
3) Mandrel pigs. Steel pigs are more long-life and long-term pigs comparing with the foam and solid-cast plugs. Their main part is steel body, where easily replaceable sealing cups and discs can be mounted. Mandrel pigs are used for displacement, batching, cleaning and inspecting the inner wall of pipes. Moreover, to remove deposits on the inner side wall, mandrel pig can be equipped with various brush: circular, spring-loaded or wrap around. To expand the functionality, gauging plates, transmitted cavities, articular joints and magnetic packs can be added. One more advantage of mandrel steel pigs is the possibility to change the wearing components, such as cups, discs and brushes, thereby offer a new pig (4). Different variations of mandrel pigs are shown on Figure 2c.

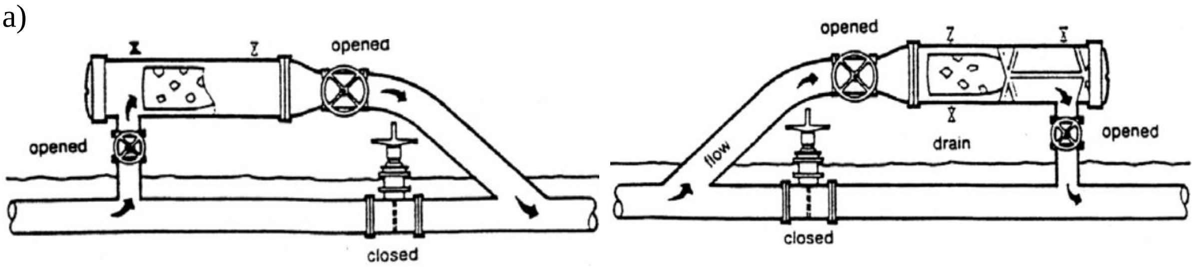
a) b) c)

Figure 2 - Types of pigs a) foam pigs (4); b) solid cast pigs (4); and c) mandrel pigs (4)

2.3 Pigging unit

The total pieces of equipment which are necessary for the pig work inside the pipe are called pigging unit. In most of the cases pigging unit include one single (simple pigging unit) or several pigging lines connected by switches (branched pigging unit). The minimum requirements is to have one launching and one receiving station. Figure 3 shows these two stations mentioned. The combination of pigging unit and all different procedures that can be done in this unit is called pigging system (2).

a)



b)

Figure 3 - Pigging equipment: a)launching station and b) receiving station (5)

By the direction of pig travel inside the unit there are found three types: forward pigging (pig plug travels in the same direction as product), reverse pigging (pig plug travels in opposite direction of product) and bidirectional pigs (plug can travel in both forward and reverse direction).Thus the pigging systems differ as open and closed. In an open system pig have one-directional movement: from launching to receiving stations, then pig is manually removed from receiving station and returned to the start. In closed systems, pigs are located inside the pipe for its total service life (2).

Moreover, the pigging system can be defined as one- and two-pigs systems. One-pig system (OPS) allows only one pig to be located and operate inside the pipe, when two-pig system (TPS) allows two, three and more rarely four and more pigs be inside the pipe.

2.4 Pipelines problems

Old pipelines are not designed or equipped to accommodate pigging activity, because in previous years pigging was not a maintenance alternative that designers considered (6). Thus, many pipelines were not capable for pigging of any kind. These pipelines might have difference in diameter sizes, short (or tight) bend radius or unsuitable branch connections. Some pipelines systems were equipped with reduced or square-shaped port valves and most likely without pig launching/receiving stations. This is common problem for most of the pipelines in oil and gas industry, which were built during and after World War II and are still in use. Nowadays, there are many different alternatives to improve the maintenance of pipeline systems that try to overcome the current constrains.

2.5 Requirements for piggable pipelines

In any industry, not every pipe must be piggable, there are a number of non-piggable lines, for example, propellant lines, product supply lines, etc (2). Nowadays there are found standards setting requirements for pipelines in order to be considered as piggagle. In Norway, there are standards developed by the Norwegian Technology Centre called *Norsk Sokkels Konkuranseposisjon* (NORSOK). For example the NORSOK U-001 Rev 3, October 2002 “Subsea production systems” (7) is one example that includes a section about piggable pipes, establishing conditions for a pipe to be piggable as follows:

1) Bends in the pipes should have radius at least three times the pipe ID.

2) Bends, valves, branches and their combination must be separated with a straight leg with length at least three times the pipe ID.
3) Pipes should have constant ID.
4) In piggable pipes branches should be designed to avoid accumulation of deposit from the pigging. These brunches shall intersect above centreline of the headers.
5) Fabricated tees and fittings shall be designed to suit for pigging.

The listed specifications are basic requirements for piggable pipelines. However, depending from industry, pipe length, surrounding environment or price for pipeline system, some extra requirements can be set up. Following this specification pigging of the pipelines will be effective and successful.

2.6 Pipelines material

Choice of material in each particular case depends from its application, industry standards, surrounding environment, price point, etc. For example, in chemical industry the most commonly used stainless steel types are DIN 1.4541 (AISI 321), DIN 1.4571 (AISI 316 Ti), AISI 304L, AISI 316L, etc. (2). The pipes made of unalloyed carbon steel also can be used if they satisfy the requirements listed in standards like DIN 1626 or DIN 1629, welded pipes of unalloyed steel and seamless pipes of unalloyed steel respectively (2).

More specific and rarely used are nickel-base alloys (Incoloy, Hastelloy). These materials are highly corrosion resistant and can be used in chemical industries.

Nonmetallic (plastic) pigging line can be substituted for coarse cleaning. They are standardize as pressure pipes (up to 16 and 25 bar) and as sewage pipes. Materials which are commonly used are: polyvinyl chloride, polyvutene, glass-fiber-reinforced epoxy resin etc. (2).

In individual cases, for demonstrative, laboratory or mini plant application can be used piggable glass pipes.

2.7 Piggable valves and other fittings

Valves and other fittings are non-separable part of pipelines; therefore, it is very important for them to follow the concept of being available to pigging activity. Not any valve can be used in piggable pipeline, for example standard commercial valves, ball valves with reduced diameter, stop cocks, etc. are not piggable. They can be used at the outlets of launching and receiving stations or for the propellant supply, but not inside of piggable pipeline (2).

Selection of piggable valves is particularly important, they must be optimally adapted for the specific application. The brief listing of requirements can be done:

1) Valves should have the same inner diameter as the pipe.
2) They should have guide bars at branches of the valves.
3) The piggable valves should allow cleaning and be free from pockets (no dead space).
4) They must be suitable for used type of pig (seal, lip, spherical or solid cast pigs).
5) Pig sensors, pressure-relief and ventilation nozzles must be installed accurately.

Moreover, product's properties also should be considered. For example, hardening, adhesive and abrasive products can limit the range of application of a valve (2).

One more often used part in the pipelines is the T-pieces or tees. Standard tees are rarely used for piggable pipes, instead special fittings are installed such T-ring valves or product branches, possibly equipped with integrated pig trap and ball valve (2). Good alternative for T-pieces are Wye fittings, which allow lateral connection with trunk lines that can be pigged from either the lateral line or through the trunk line (8). Wye fittings have symmetrical and asymmetrical design, which are shown on Figure 4.

a) b)

Figure 4 - Wye fittings in a) symmetrical design and b) asymmetrical design (9).

2.8 Energy considerations

To push liquid through the pipeline it is necessary to make consideration about required energy. To determine required pressure, velocity or profile of the pipelines, engineers use Bernoulli Equation, (Equation 1). This equation represents the energy balance in the system by combining pressure energy, kinematic energy, potential energy, and losses inside the pipeline for an uncompressible fluid in steady state condition between two location named "1" and "2" connected through a streamline.

$$\frac{P_1}{\gamma} + \frac{1}{2g}v_1^2 + z_1 = \frac{P_2}{\gamma} + \frac{1}{2g}v_2^2 + z_2 + h_{losses}$$ *Equation 1*

where P – pressure, *Pa*

$\gamma = \rho g$ – specific weight of fluid, N/m^3

ρ – density of the fluid, kg/m^3

g – the gravitational constant, m/s^2

v – velocity of the flow, *m/s*

z – height of the particular point in pipe, *m*

h_{losses} – losses in pipelines, *m.*

There are two types of losses in the pipelines: major (or head) and minor (or local). Major losses occur due to friction along the length of pipe and they can be defined with the Darcy-Weisback equation (Equation 2).

$$h_L = f\frac{Lv^2}{2Dg}$$ *Equation 2*

where f – friction factor, [-]

L – length of the pipeline, *m*

D – inner diameter of the pipe, *m.*

The friction coefficient can be found by using Moody diagram, which relates f, Reynolds number *Re* and relative roughness. Reynold's number defined as shown in Equation 3.

$$Re = \frac{\rho v D}{\mu}$$ *Equation 3*

where μ – dynamic viscosity of the fluid, *Pa*s.*

Minor losses refer to the energy losses near the components like elbows, exits, fittings, etc. The general way for calculation minor losses are shown in Equation 4.

$$h_m = \sum_{i=1}^{n} K_i \frac{v^2}{2g}$$ *Equation 4*

where K_i – loss coefficient for every inner component. This coefficient can be found in related tables.

This calculation will be used to control the flow inside the experimental loop, to find characteristics of pump, valves and other components.

2.9 GPS location method

The Global Positioning System (GPS) is the satellite based navigation system (10). This system includes two main part: satellites and receiver, which can be found in any smartphone or car navigation gadgets.

There are several navigation systems, which different countries uses:

USA – NAVSTAR

Russia – GLONASS

India – IRNSS

China – Bet-Dou-2

EU – GALILEO

Chinese and Indian navigation systems are available to use only in their countries, when the rest of GPS can be used world-wide. The American NAVSTAR is now identified by the GPS abbreviation and used alike. It is the most widely-used and easy-access system from all listed above. Discarding of all old navigation systems, GPS is not a surface-based system. Until earliest 50th of XX century (also known as Space age), all mechanisms, which were used to map and navigate the earth, were connected to the planet's surface. GPS has provided totally new solution for the positioning problem. It uses the three-dimensional rectangular coordinate system. One axis is fixed with the axis of earth rotation. The other two axes are fixed at defined and essentially arbitrary location (11). Located on the Earth GPS receivers use the signals from satellites to make difficult calculations of the X,Y and Z coordinates of the receiver (11).

GPS satellites do not track the receiver`s location, they basically broadcast a signal which is used by GPS receiver (12). The Global Positioning System is a network of satellites (for example NAVSTAR has around 30 satellites), receivers and super accurate clocks, all pulled together with math. This process required a lot of information and conditions.

First, it needs an exact time. The most accurate measure of time human have is a constant, the predictable vibration of the electrons in an atom. The atomic clock can provide the accuracy to nanoseconds, which is crucially important (12). It does not means that any GPS unit should have an atomic clock. As long as the unit`s clock is good, it is going to receive regular updates from the nearest observatory to keep in on track.

Second, a satellites network should also know the time. Until October 19 2015 American system NAVSTAR had 30 GPS satellites with 3 atomic clocks on board, as well as, transmitters which send microwaves on the planet. This system is flying at around 11000 km/hr about 20000 km above Earth surface and it is maintained by American Air Force (12). Those transmitted signals tell the user his location on the planet. GPS signals are sent on exact intervals, they carry with them information about which satellites sent it, location of this satellite and all satellites in a system in a very precise day and time (12).

Any GPS receiver have to have very precise time, because microwaves travel at the speed of light and they take fraction of the second to reach the Earth. The receiver can tell where each satellite is by the difference in a time lag from the signal. Using the mathematical principal of trilateration, the GPS unit can determine the exact location. A sphere can be drawn around each satellite, indicating the time lag from each and the overlapping point, where all of them intersect in the exact location. The more satellites GPS unit can see, the more accurate location in will defined (12). A simplified scheme shown on Figure 5.

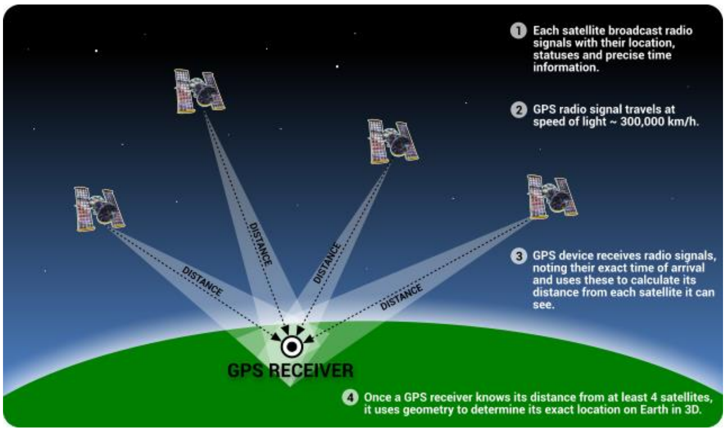


Figure 5 - Simplified image of GPS arrangement (13)

2.10 Corrosion detection methods

2.10.1 Definition of corrosion

The primary definition of "corrosion" is the metal's unwanted oxidation on its surface caused by the environment (14). Corrosion is a considerable obstacle for all metal- based construction. The corrosion mechanism is based on electrochemical reaction with corresponding agents. The usual oxidation agents are water and/or air.

The consequences of corrosion existence on the metal surface should not be underestimated. Detection and measurement of corrosion in earliest stages will help to define proper treatment and extend the lifetime of the pipeline system.

There are found several main types of corrosion:

1) Uniform attack. It is the most commonly met form of corrosion. It is characterized with an electrochemical or chemical reaction which expands uniformly over entire exposed surface or large area (15). The metal becomes thinner and at some moment fails. The example of uniform corrosion is shown on Figure 6a.

2) Galvanic or two-metal corrosion. When two dissimilar material immersed in a corrosive or conductive solutions there is a potential difference exists between them. If these metals are placed in a contact, their difference of potentials cause electrons flow between them. The less resistant metal behaves as anodic and more resistance-as a cathodic. In this type of situations, cathode or cathodic material corrodes very little or not at all meanwhile the anode suffers corrosion (15). Example of galvanic corrosion is shown in Figure 6b.
3) Crevice corrosion is an intense and localized corrosion which occurs within crevices or other shielded areas on metal. This defect is often associated with small volumes of stagnant solutions of gasket surfaces, lap joints, holes, surfaces deposits, and crevices under rivet heads or bolts (15). The example of crevice corrosion can be found on Figure 6c.

a) b) c)

Figure 6 - Example of a) uniform corrosion; b) galvanic corrosion and c) crevice corrosion (16)

4) Pitting is a type of localized corrosion that results in holes in a metal. Pits may be described as a cavity or hole with the diameter about the same as its depth. Pits can be isolated or so close together that they look like a rough surface. Pitting is one of the insidious and destructive forms of corrosion, which can cause failure in equipment with only small percent weight loss of the structure (15). Figure 7a shows the example of pitting.
5) Intergranular corrosion. In most of corrosion cases, the metal grain boundaries behave in the similar way as the grains themselves. However, in some condition, the grain boundaries can be defected, when the rest of material remains unaffected. It leads to metal disintegrating and loses of its mechanical properties. This type of defect can be caused by the presence of impurities in the boundaries or to local depletion of one or more alloying elements (16). Example of intergranular corrosion is shown on Figure 7b.
6) Selective leaching is a corrosion process characterized by the removal of one element from a solid alloy. The common example is the dezincification, i.e. removal of zinc from brass alloys. In other cases, aluminium, iron, chromium, cobalt and other elements are removed.
7) Erosion and cavitation corrosion is caused by the movement between a corrosive agent (fluid) and a metal surface. In this type of corrosion the mechanical aspect of the movement has a important role. Also the friction and wear phenomena can be involved. This process leads to the creation of valleys, grooves, wavy surfaces, holes, etc. with a specific directional appearance.

Most of soft metals (cooper, lead, etc.) or those metals whose corrosion resistance depends surface film (aluminium and stainless steels) are often affected by this type of corrosion (16). Example of erosion-corrosion in cooper pipeline is shown in Figure 7c.

8) Stress-corrosion cracking is a process of initiation of cracks and their propagation, possibly until the complete failure of a component, because of combined action of corrosive medium and tensile mechanical loading (16). This defect leads to a complete failure of the structure by the time of few minutes to several years.

a) b) c)

Figure 7 - Example of a) pitting corrosion; b) intergranular corrosion and c) erosion-corrosion (16)

All this types of corrosion can be found in a pipeline system in different parts of it. The most probable distribution of different types of corrosion is listed in a Table 1 (17).

Table 1 - Types of corrosion and its typical location in pipe system

Type of corrosion	Typical location in the pipe system
Uniform corrosion	Valves, pumps, shafts, tanks, bolt heads
Galvanic corrosion	Joints (connection between carbon steel and brass valve, or transition to cooper pipe)
Crevice corrosion	Flanges, lap joints, rivets
Pitting	Pinholes
Selective leaching	Brass pipes
Intergranular corrosion	Pipe surface areas away from the welded parts
Erosion corrosion	Bends in the pipelines, pipe connections
Stress corrosion cracking	Stainless steel pipes

2.10.2 Detection methods

There are variety of methods to detect and measure corrosion on surfaces, they differ in the level of the results precision and accuracy.

1) Spectroscopic method is often used to detect various mechanical defects in different classes of material (18). Impendence spectroscopy is a multi-functional technique, which found application in corrosion, surface coating characterisation, sensor development and corrosion. For inspection, the electrochemical system is subjected to the sinusoidal voltage of variable frequencies and low amplitude. At each frequency different processes evolve with different rates, which allow to distinguish them (19).
2) Terahertz radiation is non-destructive technique that offers a high-resolution and non-contact means of inspecting corrosion. The wave frequency is between 100 GHz and 10 THz and wavelength of 300 µm at 1 THz. This radiation is able to penetrate and inspect defects in nonconductive materials and is reflected from metallic materials (20). This method is capable to detect hidden corrosion under surfaces, surface roughness and evaluation of composites (21).
3) Fiber optic method based on channelling and manipulation of light through an optical fiber and measuring the difference of the output power or intensity of the light (21). With the suitable coating the fiber optic sensors can be used to detect corrosion, water or metal ions in the structure.
4) Eddy current method is tested and tried technique, which offers effective and wide range application in different areas. This method is based on creation of circulating eddy currents in the conducting surface of a material when AC current flows in a coil close to the conducting surface. When this coil is passing over the surface, any changes in geometry, material`s physical properties, and conductivity will interrupt or reduce eddy current flow that will lead to reduction in coil loading and increasing its impedance. Thus, by monitoring the voltage across the coil, variation in its amplitude and phase shifts can be used to detect changes in material properties and structure (22).
5) Ultrasonic detection methods provides the possibility of identifying and analysing flaws and corrosion in the metal. This method offers reproducible results for analyses of welding joint or whole structure. This technique uses ultrasound probes, which can function as transmitters or receivers. By analysing the signals test expert can detect corrosion in the examined structure (23).
6) Magnetic flux leakage is a widely used, non-destructive testing method for corrosion and pitting detection is a steel structure. This method is often used in pipelines and storage tanks assessments, but the principle finds application in any industrial sector. The technique involves magnetizing a ferrous material to saturation level with very powerful magnetic field. In areas where object has no flaws, the magnetic flux remain undisturbed. Where there is an external or internal metal loss, the magnetic flux “leaks” from the structure. Test expert can interpret these leaks and detect the corrosion (24).

7) Visual inspection is the simplest form of testing that can be performed without any aids when there is a physical access to the object. The test expert can determine type and degree of corrosion. Better documentation and description can be done by using sketches or photographs (25).
8) Radiography method use the penetrating of short electromagnetic wave, which can be X-rays generated by X-ray equipment or γ-rays from radioactive isotopes. When the wave passes through the structure, the material absorbs part of its energy. Existence of cracks and corrosion vary the amount of energy passing through. The picture of energy distribution can show to test expert where defects in a structure can be found.

Some of the listed methods can be adapted to be used in pig plugs.

2.11 Roughness measurement methods

2.11.1 Definition of roughness

Roughness can be defined as the quality of having irregular or uneven surface. The real surface geometry is complicated and it can not be described as a finite number of parameters, but the important conclusions about surface quality can be done by using several of them. One of the most important parameters which is used to characterize surface quality is the amplitude parameter. They are used to measure vertical characteristics of the surface deviations, for example arithmetic average height (Ra). This parameter is easy to define and easy to measure. Ra is calculated as absolute average deviation of the roughness irregularities from the mean line over the length of the sample (26), see Equation 5.

$$R_a = \frac{1}{n}\sum_{i=1}^{n}|y_i|$$

Equation 5

,where n – amount of taken measurements

y_i – value of vertical characteristics of the surface deviations.

Roughness in the pipeline has a great impact on the quality and performance. For example, it increases friction between liquid and pipe, which lead to energy losses. That's why this parameter is an important characteristic required for Moody diagram and further energy calculation (27).

2.11.2 Detection methods

There are two main principal of roughness measurements: contact and non-contact. Contact type method uses the tip of the stylus, which is directly touches the surface of the sample. When the stylus passes over the sample, it falls and rises together with the roughness on the surface. The measurements of the stylus movements are recorded and used in roughness characteristics calculation (28). The unit for contact measurements called contact profilometer and its principal is shown on Figure 8.

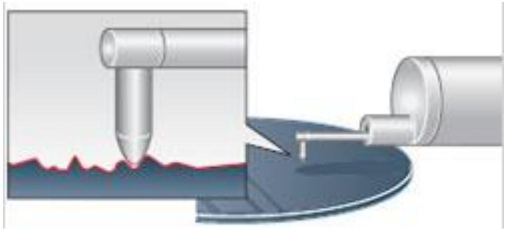


Figure 8 - Principle of contact profilometer (28)

Non-contact methods use different approaches to receive the information, but as they are non-contact, these systems do not harm the sample and can be used to measure soft or viscous materials.

Optical methods are based on the electromagnetic radiation (light wave) incident on a surface, and its behavior after being reflected: specularly, diffusely or both combined. There is variety of optical methods that use the same principal but different approach to collect and analyze information. Some of these methods are taper-sectioning, light-sectioning, specular reflection, diffuse reflection, optical interference, etc. (29).

One more approach of roughness measurements using the non-contact methodology is scanning probe microscopy. This is a family of instruments based on atomic force microscopy and scanning tunneling microscopy. The principal of STM is straightforward. A microscope`s metal tip brought close to the examined surface, when both of them are connected to the electrodes and subjected to the convenient operating voltage. The important value is the tunneling current, which is creating between electrodes. The tip passes over the surface and the tunnel current between two surfaces is recorded. The received measures can be transformed into material roughness characteristics. However, this method is suitable only for the conductive materials (29).

The atomic force microscope allows making inspection of both conductors and insulators. The AFM relies on a scanning technology to produce high-resolution, 3D images of a sample surface. AFM measures ultra-small forces present between the tip on AFM and surface. The tip is connect with a flexible, ultra-small mass cantilever beam, which motion is being recorded (29). Obtained values are used to build the image of surface and calculate the roughness. The principal of AFM operation is shown on Figure 9.

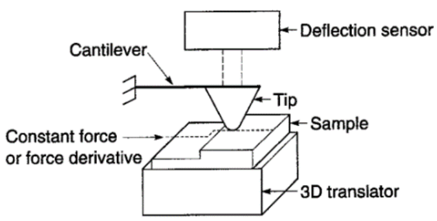


Figure 9 - Principle of atomic force microscopy method (29)

Roughness measurement methods can be adapted for application in pig plugs and used for pipeline inspection.

3 Conceptual design

This chapter is aimed to summarize given theory and make an overview of future design. Experimental loop to demonstrate pigging activity will include following parts: pipeline, launching and receiving stations, pump, valves, pig plug and instrumentation for the pig.

Pipeline should satisfy the requirements for being «piggable». List of related characteristics was given in section 2.5. The pipeline system will be friendly with user and aimed to give the best understanding of the pigging activity principle, route tracking and collecting information about inner surface.

Launching and receiving stations will be done and located to show their functionality in the best way. Pipeline components, as pump and valves, should provide the fluid movement through the system and complete the functionality of the stations.

The pig plug will be designed to show cleaning activity. Moreover, it can be equipped with proper instrumentation to show route tracking, measure corrosion and roughness of the inner pipe surface.

To have the experimental loop in proper position and orientation, the installation support will be also designed.

The final step is to plan the connection between pig plug and PC. This step required a deep understanding of different types of signals and connections. In frames of this thesis, only suggestions about connections will be done. The interface will be presented as the desired layout, which will show necessary information, collected by pig plug.

Part 2

4 Collecting data

This chapter implies collecting data about workshop possibilities and available equipment, overview of the safety requirements and recommendations.

4.1 Workshop

The experimental loop will be installed in UiT Camous Narvik. The workshop is a part of Faculty of Science Engineering and Technology and have a diversity of equipment like manufacturing machines, robot manipulators, cold chambers, different testing stands and layouts. Designing loop should be a part of testing facilities in this workshop and be used during the study program to demonstrate the pigging activity principle. To make the operation of experimental loop effective and beneficial, its design should fit the existing workshop in size and functionality.

First, the physical dimensions of experimental loop should be suitable for the workshop and allow to place it indoors in vertical or horizontal position. Second, in case the stand will be placed vertically or hang in the wall, measures to handle the weight of the equipment will be incorporated to the design. Third, it is advised to use the workshop existing facilities and supplies. Moreover, the loop should be placed according to safety requirements for laboratories and fire safety regulations.

4.2 Safety requirements

Pipeline with compressed air or pressed water can be classified as pressurized system and should satisfy the requirements, which are set for this type of systems. Respective information can be found in «Health and safety in engineering workshops» book, prepared by Health and Safety Executives organization. This book is a part of Health and Safety Guidelines series, which covers requirements and recommendations for personnel work in different areas and industries. Pressurized systems should satisfy following rules:

1) All systems should be constructed, designed and installed to prevent any possible danger.
2) All systems should be properly maintained.
3) Repairs and modifications should not cause any danger.
4) Laboratory must have a written instructions for examination of certain pressure vessels, such as steam boilers, air receivers, pipework and fittings, drawn up by a competent person.
5) Test procedure should have written scheme and must be carried out by a competent person.
6) When it is needed, the pressure system should be isolated from personnel and special installation should be done to prevent injuries.
7) The system should have an appropriate indication of state on work and state off work, to warrant

the personnel. (30)

This list cover the general rules, which should be satisfied for pressurized systems. Moreover, the installation and operation should follow the «Safety of pressure systems» written by HSE. The Pressure Systems Safety Regulations 2000 (PSSR) covers the design and safe use of pressure systems. The aim of PSSR is to prevent injury from the hazard of stored energy (pressure) as a result of the failure of a pressure system or one of its component parts. (31)

Regarding fire safety requirements, rules from “Fire safety risk assessments for factories and warehouses” should be followed:

1) Installed equipment should not create extra fire hazard while using according the manual.
2) If possible, equipment should not use flammable liquids.
3) All electrical components should be installed and operated according electrical safety rules.
4) Equipment is located in the way, that personnel should travel less than 30 m for closest fire extinguisher.
5) If equipment is located near fire escape, minimal width of the escape route should be kept 750 mm. (32)

5 Design of experimental loop

This chapter will cover the main stages of design process for the experimental loop. Design process of product involves several phases. With the fulfilling of these phases, ideas will transform to the solution that in best way will solve the current problem. Design of experimental loop is initiated by the UiT and will be used as a part of its facilities. Thus, design process will be applied to create a product, which will satisfy the existing set of requirements. From all stages, describes in Nigel Cross book “Engineering design thinking”, only most relevant will be performed for the experimental loop design.

First step is to clarify objectives for the future product. The aim of this step is to identify design objectives and relationships between them. After first stage, the structure of experimental loop will be divided for following parts: pipeline, launching and receiving stations, pig plus and installation. Further design process will be performed for every loop component separately, but all parts will follow one design intent.

Second step is setting requirements, where designer should find answers on questions: what properties must designed solution have? What properties must it not have? Third step include generating and evaluating alternatives for the final product. Here the general concept of geometry and functionality of the final product should be chosen. Design of some components is dependent from other parts of experimental loop, for example, orientation and geometry of launching and receiving stations are strongly dependent from pipeline geometry. These parts will be designed in most suitable configuration. The final step will cover the detail design, 3D modeling, choice of required components and list of used materials.

5.1 Clarifying objectives

It is significant that each member in design team understands and follows the same objectives in product design. To define and concretize task aims, «The Objectives Tree» method has been used. In this method, objectives are presented in hierarchical structure, where it is easy to match relationships and intersections between them: working down the tree a link indicates how a higher-level objectives might be achieved; working up tree a link indicates why a lower-level objectives are included. (33)

The objectives tree, which is presented in Figure 10, shows the main objective for experimental loop, which are associated with safety, convenience, manufacturing and assembly. Then these main objectives are divided in sub-objectives: safe to use, being easy to manufacture, easy to operate etc. Moreover, to clarify the respective objectives, they have been separated for users (teachers and students) and workshop. All these objectives need to be satisfied in the end of design process and be realized in final product.

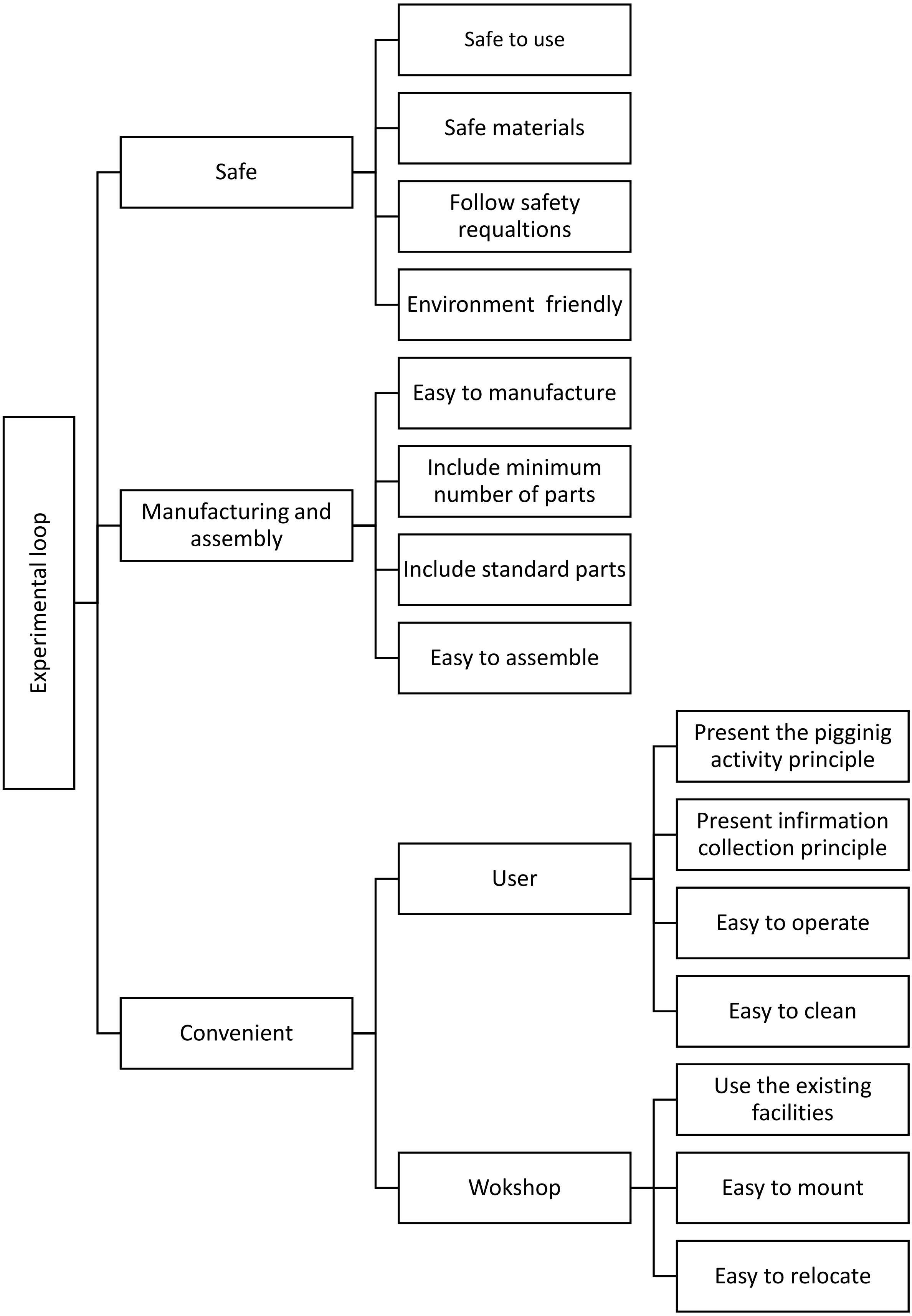


Figure 10 - The Objectives tree

5.2 Setting requirements and constrains

Setting requirements for the final product will result in a requirements list. This document performs the specification against which the success of the project can be seen. During preparing a particular requirements list it is important to clearly develop the goals and the conditions under which they have to be met. The resulting requirements can be separated as *demands* or *wishes*.

Demands are requirements that must be met under all circumstances; in other words, if any of these requirements are not fulfilled the solution is unacceptable. Wishes are requirements that should be taken into consideration whenever possible. (33) List of requirements for the experimental loop can be found in Table 2.

Table 2 - Requirements list for pipeline components.

Nº	**Requirements**	**Pipeline**	**Launching and receiving stations**	**Pig plug**	**Installation**
	<u>Geometry</u>				
1	Few parts	W	W	W	W
2	Geometrical dimensions	1500x150x2000*mm*	-	-	-
3	Weight	Max 15 *kg*.	-	Max 0,1 *kg*.	Max 5 kg
4	Compatible with designed pipeline structure	-	D	D	D
5	Be designed for cleaning activity	-	-	D	-
6	Be designed to hold the shape of experimental loop	-	-	-	D
7	Maximum weight to hold	-	-	-	D
	<u>Material</u>				
8	Light-weight materials; low-density materials	D	D	D	-
9	Transparent materials	D	W	-	-
10	Working pressure not less than 4 bars.	W	-	-	-
	<u>Safety</u>				
11	Non-toxic materials	D	D	D	D
12	Satisfy safety requirements	D	D	-	D
	<u>Ergonomics</u>				
13	Easy to start/stop; all parts should be easy reached by teacher and students	D	D	D	-
14	Easy to clean; can be cleaned at 5 minutes	W	D	W	W
	<u>Production</u>				
15	Use standard part and components	D	D	W	D
16	Simple components production	D	D	W	D
17	Use well known production techniques	D	D	D	D
	<u>Life expectancy and Recycling</u>				
18	Life expectancy 20 years in respect of amount of use and wear out	D	D	D	D
19	Easy to recycle; recycle without special restrictions	W	W	W	W

20	Environment safe	D	D	D	D
21	<u>Cost</u> Price	Up to 3000 NOK	Up to 5000 NOK	Up to 1000 NOK	Up to 1500 NOK

5.3 Design of pipeline

Pipeline is the major part of the experimental loop. The pipeline geometry will impact on installation method, preferred work mode, choice of material, required support, installation etc. In this chapter the design of pipeline will be done. Requirements and constrains for the pipeline can be found in Table 2.

5.3.1 Alternatives

This chapter will include several design solutions for the pipeline. These alternatives should follow objectives and satisfy the listed requirements. The evaluation of the alternatives will be done based on experience and preferred configuration of final product.

Geometry

Geometry of the pipeline should be simple and at the same time give the student clear understanding of the pigging activity. These requirements cover demonstration of pig entering in system, moving in straight and bended parts of pipeline and be extracted from the system. Some of possible designs are shown further.

First alternative is the simple open geometry loop, i.e. pig can move through the pipe only once and should be removed and reinstalled for next use. All pipeline lies in one plane and have U-shape.

Figure 11 – Alternative 1: open geometry pipeline.

Second alternative is open system, where pig enters the pipeline in the launching station, goes for one route and should be extracted in receiving station. This system has O-shape geometry with two separate exits for launching and receiving stations.

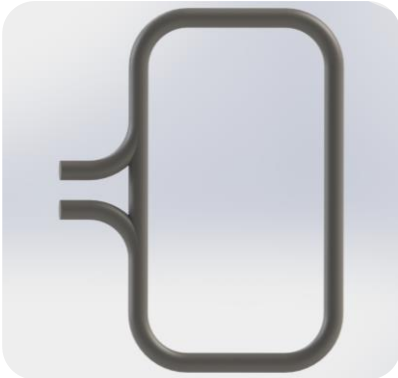


Figure 12 – Alternative 2: close geometry pipeline.

Third alternative covers a variety of three-dimensional structures, which can have several enters and exits for the pig, provide one or several routes for pig travel, etc. This system requires complicated parts and components, advanced assembly process and outer control system.

Figure 13 – Alternative 3: three-dimensional geometry pipeline.

Orientation and installation

Experimental loop stand can be oriented in two directions: vertical or horizontal. Vertical orientation need less area in workshop and users can look at the stand «face-to-face», on the eye-level. In this case experimental loop can be hanged on the wall or on special vertical support, which can be moved inside the lab if needed. Horizontal orientation will require more space and users will look down at the stand. Installation for this case should be as a permanent or movable platform, which will support the pipeline in the position.

The choice for the pipeline design should be done from the described alternatives. Based on the workshop layout in UiT, restrictions for place and area and at the time need to make a good demonstration of pigging activity, for further work alternative 2 will be chosen. Based on the same demands, the pipeline will be designed in vertical orientation with the possibility to easy remove it and relocate. This design satisfies the requirements, will fit in the workshop and will be a good experiment for teachers and students in UiT.

Extra functionality

Geometry of the pipeline can provide extra functionality to demonstrate data collection. One of the parts of the pipeline should be exchangeable, i.e. one segment can be replaced with segment made from other material. To make this possible, in lower horizontal level, the middle part will be connect with universal slip-slip unions. This connection will allow to change the pipe segment during the experiments. Design and choice of the components will be given in further chapters.

5.3.2 3D model

The 3D model of pipeline geometry will be done by using SolidWorks software and the design is shown in Figure 14.

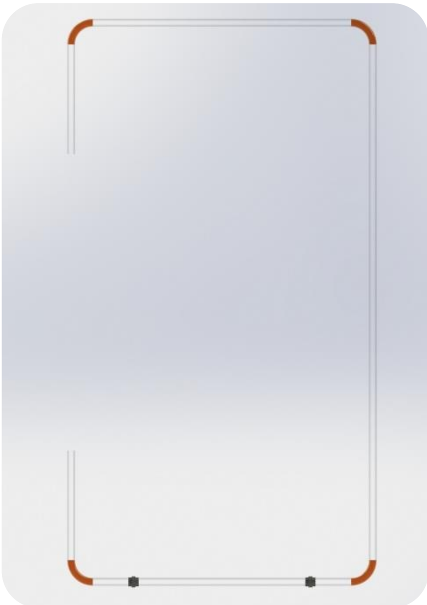


Figure 14 – 3D model for the pipeline geometry.

5.3.3 List of materials

Once the configuration is selected the materials required to build it, must have a balanced structural strength, that guarantees that the system have no major different between the pressure and load capabilities of the different elements in the system. In the final selection for material the weakest part is the pipe itself having a maximum limit for internal pressure of 4,3 bar, meanwhile the fitting and the glue are able to support more than that.

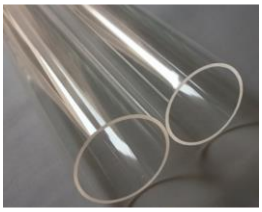
The list of material for this section of the equipment contains 4 elements summarized in . However, the specific details of each part is given below in . The suggested configuration implies the used of two different material, Plexiglas and PVC which are compatible used glued attachments.

The combination of these materials combine the possibility of having visual access to the pig itself and the usage of commercial elements which will reduces considerably the cost over homemade connections.

Table 3 – List of required materials.

Straight segments	Total: 5820 *mm* *Pipe 25 mm nominal diameter* *6 sections for 1 m*
90º bend	*Bend 25 nominal diameter* Amount: 4
Unions	*Union 25 nominal diameter schedule ZZ* 4
Glue	1 can

Table 4 – Description of pipeline components.

	Pipe	90º bend	Union
Picture			
Material	Plexiglass	PVC	PVC
Outer diameter (mm)	32	38	32
Inner diameter (mm)	24	32	0.093 *kg*
Wall thickness (mm)	3	0.074 *kg*	-
Mass/lengh (kg/m) or Mass (kg)	0.3 kg/m	-	-
Maximum inner pressure (bar)	4.3	16	10
Max. safety stress σ_{max}. (up to 40°C)	5..10 MPa	-	-
Modulus od elasticity Et (short-time value)	3300 MPa	-	-
Production company (example)	Reference (34)	Reference (35)	Reference (36)

Cementing glue

To connect the pipe segments together, the cementing glue will be used. This glue should provide permanent and durable connection between the parts. This glue will connect the PVC to PVC and Plexiglas to PVC parts together. The recommended glue can withstand the inner pressure up to 10 *bars* and widely used in pipeline industry. Description of it can be found in Table 5.

Table 5 - Cementing glue.

Glue	
Used for material	PVC-U, PVC-C
Maximum inner pressure	10 *bar*
URL	Reference (37)

Drawing for all designed part can be found in Appendix 1.

5.4 Design of pig plug

5.4.1 Requirements and constrains

Literature study shows big variety of pig plugs of different shapes and functions. However, this thesis is aimed to demonstrate a cleaning activity, so the pig plug will be design to perform this particular function. Requirements for the pig plug can be found in Table 2. Moreover, the pig plug can perform extra functions as collecting information about corrosion, roughness and travel route. Instrumentation for this functions will be chosen in next chapter, 3D design and list of required materials will be given further.

5.4.2 Concept design

The selected pig plugs corresponds to the type Mandrel pigs, described in section 2.2: Geometry of the pig will be a metal body equipped with several flexible plastic disks, which are designed in theory to remove and collect debris from inner surface of the pipeline, but in this experimental system to simulate that recollection and to sense irregularities in the pipe inner surface.

Additional functionality for the pig plug is collecting information about inner surface of the pipeline and GPS route of pig travel. This information should be collected by the sensor, installed in the pig plug and transferred to PC station, where it will be analyzed and presented on the screen.

5.4.3 Instrumentation

GPS route

Chapter 2.9 include information about principles of GPS routing. It is possible to use GPS chip as a part of instrumentation for the pig plug and get information about pig travel along the pipeline. As it was written previously, the GPS system should include two main part: satellite and receiver in Earth. Thus the pig plug should be equipped with the GPS receiver. Nowadays technology allows to create the microchip of small dimensions, which found the application almost everywhere. One of the small dimensional chip can be placed in pig plug. The GPS chip will need to receive the signal from satellite, make a calculation for the its position and after transfer the signal to the PC, where this information will be presented in the main screen.

However, the pig plug made out of aluminum, which can cause interference with the GPS signal and signal to the PC. Due to this fact, the chip will not be placed inside the metal part, but be located outside in a plastic body. This body will be connected with the thread to the aluminum body. Design of this part will be given in next chapter together with pig plug.

To track pig route the positioning module should include several parts: battery, microcontroller unit (MCU), GPS chip, Wi-Fi module and USB connection. GPS chip should receive the signal from GPS or GLONASS satellites and send them to the MCU. MCU should be programmed in the way to process the signal, make calculations and transform the information from signal to the X,Y,Z coordinates. This information should be send to the PC by use of WiFi module. This three components should work simultaneously and send the pig route in “live” mode. The PC should provide the connection with WiFi module on the pig, receive information and present it on the screen, so user can read it. Moreover, for first set up and calibrating WiFi module and MCU, it should have a USB connection with PC or provide other type of connection suitable for these purposes.

Positioning module on the pig should also have the battery to supply an energy for module components. Type of battery will depend from the voltage consumption of the components. Now most of components require 3-5V, but some of parts can use lower voltage.

All chosen components should be connected and fit in a plastic container outside of the pig plug body.

Corrosion detection and roughness measurements

Chapter 2.10 include the extended information about different ways of corrosion detection and measuring. Some of these methods can be modified and adjusted for application in pipeline industry. However, a lot of companies make a research in this area and find different approach for tracking corrosion process. These technologies are top notch and include the latest development in mechanics, optics, electromagnetics and electronics.

In frame of this thesis most of the methods can not be used due to used material, geometrical restrictions, complexity of the method itself and absent access to the latest technologies. However, there are different ways to collect information about inner surface of the pipe. One of the well known methods, that can be used in experimental loop is detecting vibration. For example, design of the pipeline provide possibility to change the pipe in lower level to the pipe with different surface characteristics. This pipe can be manufactured to have the special inner surface, which will make pig plug vibrate while passing through. This vibration can be tracked by sensor and be send to the PC. The implementation of this vibration tracking will give the students understanding the process of collecting and analyzing information about pipes.

Vibration sensor should be installed at the same way as the GPS module: sensor should be connected to the MCU and information send by WiFi module. As long as the designed pig plug already have the outer module for positioning module, the vibration sensor can be connected with the same MCU and use already established connections. On the market are found vibration sensors with miniature sensors in a dimensions within 3-8 *mm*. This type of sensors will fit the geometrical restrictions and give the required information.

The schematic circuit of this module with GPS and vibrations modules is given in Figure 15.

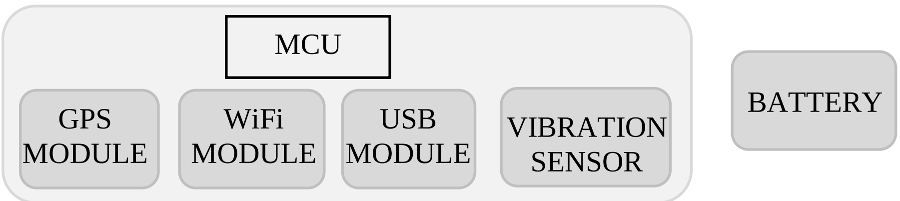


Figure 15 – Schematic circuit for the positioning module.

This thesis will not cover the detain design of the positioning module. This process requires specific knowledge in microelectronics and programming and should be done by the competent person in future work on experimental loop.

5.4.4 3D model

3D model based on concept design for pig plug is given in Figure 16.

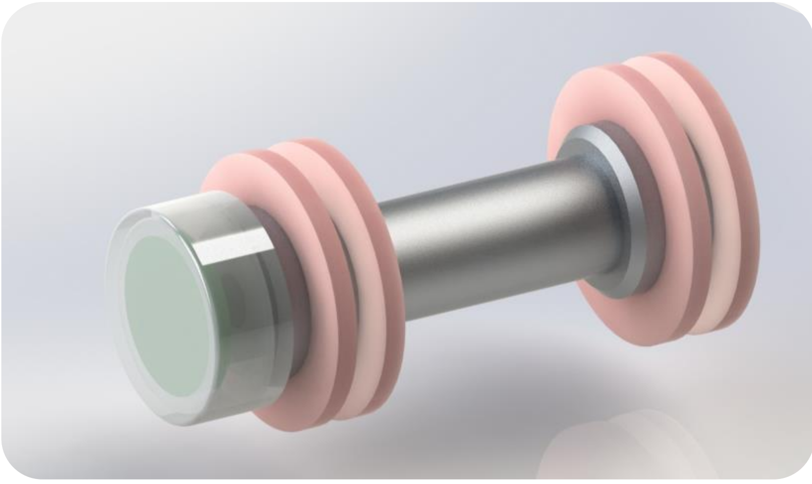


Figure 16 – Design of pig plug.

5.4.5 List of materials

The pig plug body consist of two main parts: aluminum body any flexible rings. Body can be manufactured from the ordinary aluminum cylindrical stock in UiT workshop. Preferable material for this part is Aluminum 4043. In this case body of the pig will weight 45 *g*. Drawing for the part can be found in Appendix 1.

The elastic part is designed as rings, which will be pulled on the body. Preferable material for this part is Silicone 70 shore A. This material can be purchased in the sheets of different size and colors and cut according to the drawing in Appendix 1. Physical properties for chosen material can be found in Table 6.

Table 6 - Silicon 70 Shore material properties (38).

Name	Silicone 70 Shore
Density	1250 kg/m^3
Young's modulus	1-5 *MPa*
Maximum elongation	200-800 %
Tensile strength	5-8 *MPa*

5.5 Design of launching and receiving stations

Design process for the launching and receiving stations will include list of requirements and constrains, 3D design, choice and description of valves and pump that will be used in the system. Requirements and constrains for the launching and receiving stations are listed in Table 2.

5.5.1 Conceptual design

Launching and receiving stations will be built-in the pipeline structure. The schematic view of the pipeline is given in Figure 17. The concept contains:

1) Tank with water.
2) Pump that will supply water for the system.
3) Ball valve that will open/close pipe for water supply.
4) Solid ball valve that will open/close launching station.
5) Launching station.
6) Solid ball valve that will open/close launching station.
7) Ball valve that will open/close pipe for water supply.
8) Solid ball valves that will open/close receiving station.
9) Receiving station.
10) Solid ball valves that will open/close receiving station.

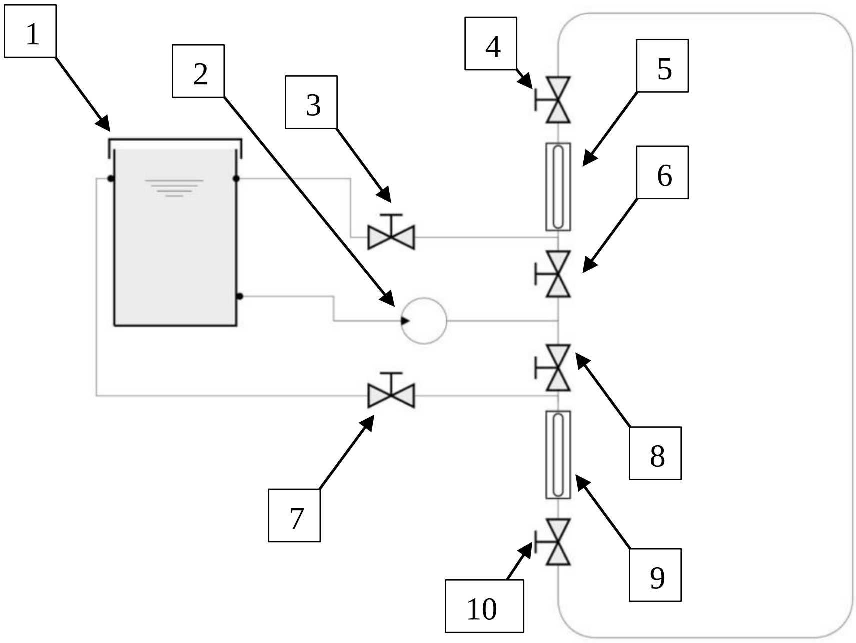


Figure 17 – Scheme on the circuit.

This design follows recommendations for the launching and receiving stations and provides the required functionality. Because launching and receiving stations have an identical design, they can work interchangeably. Thus, design of this pipeline will allow pig plug to be installed in both of the stations and travel through the pipeline in two opposite directions. Direction of pig plug will be controlled by the direction of water flow, which is set by the combination of opened and closed valves. This functionality will provide some extra demonstration of pig work along the pipeline. Different modes for the experimental loop work will be explained in chapter 6.

5.5.2 3D model

3D model of conceptual design will be made in SolidWorks and is given in Figure 18. 3D model repeats the conceptual design idea. In the top there is a solid ball valve, through which pig will leave or enter stations. Launching stations is designed as two pipes, placed one over the other, with the cut for placing the pig plug. When pig is installed inside the stations should be closed. Next step is open the valves and start the pump to get water push the pig along the pipeline. When the pig reaches receiving station, it should be opened and pig taken away for further operating.

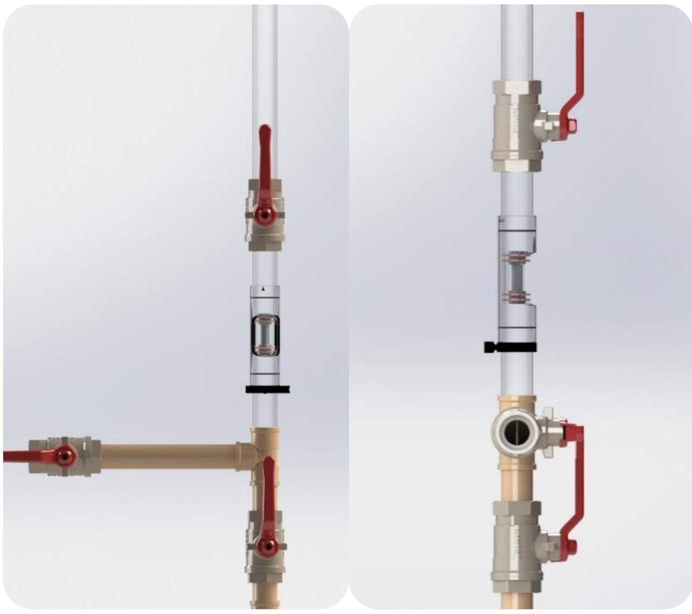


Figure 18 – 3D model for the launching and receiving stations.

Launching and receiving stations are connect with the pump and water supply tank. 3D model for the pump, tank and its connection is given in Figure 19.

Figure 19 – 3D model for pump, water tank and connection pipes.

Upper pipe line is connected with the 90^0 tee, leading to the launching stations. Pump is connected to the 90^0 tee, leading to the connection between stations. Lower line is also connected to the 90^0 tee, leading to the receiving station. Design of this part can be adjusted in case of materials for the pipeline and connections, but the layout should be kept the same.

5.5.3 Valves and pump

Valves

Conceptual design requires two types of valves: ball valves, which will be installed in the water supply pipes, and solid ball valves, which will open and close launching and receiving stations. Choice of the solid ball valves for launching and receiving stations is based on the requirements from chapter 2.5 for piggable pipelines. Thus, it is important to have the suitable type of valve for this case. At the same time, valves for the water inlet/outlet can be changed without any consequences for pipeline functioning.

For current design the similar valves will be used for water inlet, outlet and stations. Recommended models are given in List of material.

Pump

Conceptual design contains the pump that will push water and pig through the pipeline. To choose the pump it is needed to know the required energy and pump head. Respective calculations can be done based on information, given in chapter 2.7.

First, it is necessary to calculate the required force and pressure, which is required to move the pig inside the pipeline.

1) The model of the pig in the pipeline is given in Figure 20.

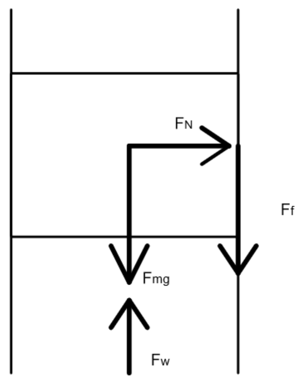


Figure 20 – Scheme of the pig in pipeline.

Where F_{mg}- gravity force, *N*

F_f- friction force between pig and pipe, *N*

F_N- reaction force from pig towards pipe, *N*

F_w- external force from water pushing pig plug, *N*

2) Second Newton's low of motion along y-direction:

$F_w = F_{mg} + F_f.$

Where $F_{mg} = m * g$

$F_f = \mu * F_N$

μ- friction coefficient between pig and pipe.

3) Gravity force is equal to:

$F_{mg} = 0{,}06kg * 9{,}81\ {}^{m}/_{s^2} = 0{,}6\ N$

4) Force F_N is the reaction force, which is created, when the elastic disks on the pig beeing compressed towards the pipe inner surface. Due to the fact, that current calculations and done to estimate the required pressure to move pig inside the pipe and do not require high accuracy, the calculation model will be simplified to the elastic model and follow the Hook's law. Thus, the general formulation of Hook's law will be used:

$$\sigma = \varepsilon * E$$ *Equation 6*

Where $\varepsilon = \frac{\Delta L}{L}$ – strain

$E = 2\ MPa$ – Young modulus for the silicon material.

From the other side, it is know that stress can be found in this way:

$$\sigma = \frac{F_N}{A}$$ *Equation 7*

Where A – cross-area of the body, *mm*^{2}.

Combination of two equations will give:

$F_N = \sigma * A = \varepsilon * E * A$

The cross-section of the disk in the direction of acting force is a rectangular with the maximum cross-section:

$A = D * h = 25{,}5\ mm * 2\ mm = 51\ mm^2$

Strain is equal to:

$$\varepsilon = \frac{0{,}5\ mm}{25{,}5\ mm} = 0{,}02$$

Substituing all found values into F_N equation:

$F_N = 0{,}02 * 2\ MPa * 25{,}5\ mm^2 = 2\ MPa * mm^2 = 2\ N$

5) Thus, the friction force can be found:

$F_f = \mu * F_N$

$\mu = 0{,}8$ (39)

$F_f = 0{,}8 * 2\ N = 1{,}6\ N$

Because pig plug equiped with four elastic disks and every one is submitted to the friction force, then $F_f = 4 * 1{,}6\ N = 6\ N$.

6) Then dragging force can be found:

$F_w = F_{mg} + F_f$.

$F_w = 0{,}6\ N + 6N = 6{,}6\ N$.

7) Pressure, creating by this force then equal to:

$$\sigma = \frac{F_w}{A}$$

Where A- area im the direction on acting F_w, which is a circular shape.

$A = \pi r^2 = 3{,}14 * 25^2\ mm^2 = 1963\ mm^2 = 1{,}9 * 10^{-3} m^2$

And,

$$\sigma = \frac{6{,}6\ N}{1{,}9 * 10^{-3} m^2} = 3500\ Pa = 0{,}035\ bar$$

This value can be converted for the meter of head:

$h_{pig} = 0{,}36\ meter\ of\ head$

The value of h_{pig} will be used in Bernoulli equation further in chapter.

To calculate the characteristics of the pump it is necessary to use Bernoulli equation, given in Equation 8.

$$\frac{P_1}{\gamma} + \frac{1}{2g} v_1^2 + z_1 + h_{pump} - h_{losses} - h_{pig} = \frac{P_2}{\gamma} + \frac{1}{2g} v_2^2 + z_2 \qquad \text{Equation 8}$$

To apply Bernoulli equation it is needed to draw the circuit and define two point, between which calculations will be done, see Figure 21. Point (1) is located in water surface in tank and point (2) – in the pipe outlet, where water returns back to the tank. Between two point there are pump, four ball valves, seven 90^0-elbows and pipeline of 6,5 *m* length.

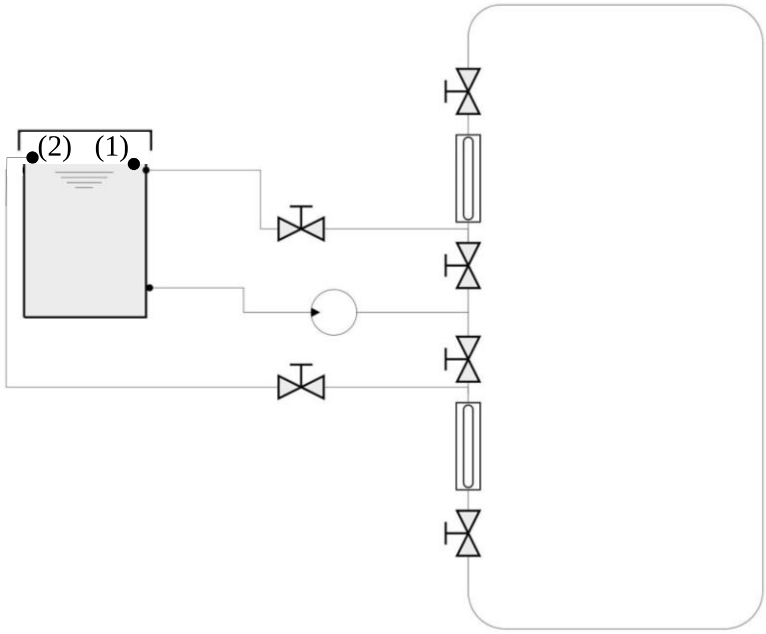


Figure 21 – Scheme on the circuit with points for calculation.

1) Initial conditions:

$P_1 = 0\ Pa$ – pressure in point (1) before the pump is atmospheric.

$\gamma = 9{,}777$ kN/m^3 – specific weight of water.

$v_1 = 0\ m/s$ – water velocity in point (1).

$z_1 = 0\ m$ – «zero»-level.

$P_2 = 0\ bar$ – working pressure.

$v_2 = 0.05 m/s$ – velocity in the point (2).

$z_2 = 0{,}01\ m$ – height of the point (2).

2) For future calculation of friction factor it is required to have a Reynolds number, which can be calculated from Equation 9:

$$Re = \frac{\rho v D}{\mu} \qquad \text{Equation 9}$$

where $\rho = 1000\, {}^{kg}/_{m^3}$-density of water.

$v = 0{,}05\, {}^{m}/_{s}$ – assumed velocity of flow.

$D = 0{,}025m$ – diameter of the pipe.

$\mu = 8{,}9 * 10^{-4} Pa * s$ - the dynamic viscosity of water.

$$Re = \frac{1000\, {}^{kg}/_{m^3} * 0{,}05\, {}^{m}/_{s} * 0{,}025m}{8{,}9 * 10^{-4} Pa * s} = 1404 \left[\frac{kg * m * m * m^2 * s^2}{m^3 * s * s * kg * m}\right] = 1404$$

Value of Reynolds number of $1404 < 2000$ gives the laminar flow in the pipeline.

Friction factor for the laminar flow can be calculated as $f = \frac{64}{RE} = 0.045$.

3) The hydraulic fluid loses some energy due to friction as it passes through the pipe. These losses can be calculated from Equation 2.

$$h_L = f\frac{Lv^{\ 2}}{2Dg} = 0,045 * \frac{6{,}5\, m * (0{,}05\, {}^{m}/_{s})^2}{2 * 0{,}025m * 9{,}81\, {}^{m}/_{s^2}} = 1{,}5 * 10^{-3} m$$

4) Minor losses for pipeline components can be found from Equation 4.

$$h_m = \sum_{i=1}^{n} K_i \frac{v^{\ 2}}{2g} = \left(7 * K_{90-\mathrm{deg}\, elbow} + 4 * K_{ball\ valv}\right) * \frac{(0{,}05\, {}^{m}/_{s})^2}{2 * 9{,}81\, {}^{m}/_{s^2}}$$

$$= (7 * 0{,}3 + 4 * 0{,}05) * \frac{(0{,}05\, {}^{m}/_{s})^2}{2 * 9{,}81\, {}^{m}/_{s^2}} = 3 * 10^{-4} m$$

5) Sum of minor and major losses is equal to:

$h_{losses} = h_L + h_m = 3 * 10^{-4} m + 1{,}5 * 10^{-3} m = 1{,}8 * 10^{-3} m$

6) Substituting all found values in Bernoulli equation:

$$0 + 0 + 0 + h_{pump} - 1{,}8 * 10^{-3} m - 0{,}36\, m = 0 + \frac{1}{2 * 9{,}81\, {}^{m}/_{s^2}} (0{,}05\, {}^{m}/_{s})^2 + 0{,}01m$$

$h_{pump} - 1{,}8 * 10^{-3} m - 0{,}36\, m = 0 + 1{,}3 * 10^{-4} m + 0{,}01\, m$

$h_{pump} = 0{,}4\, m$

7) Pump head can be converted in pressure in bar in the following way:

$p = 0{,}0981 * h_{pump} = 0{,}0981 * 0{,}4\, m = 0{,}04\, bar$

It is possible to see that the pump, required for the experimental loop should provide the outer water pressure for *0,04 bar*, and this pressure can be achieved with a big variety of pumps. Other important characteristic for pump choice is the flow rate. The flow rate for the loop can be calculated in the following way:

$$Q = A * V = \pi * r^2 * V = 3{,}14 * (0{,}025m)^2 * 0{,}05 \, {}^{m}/_{s} = 10^{-4} \, {}^{m^3}/_{s} = 6 * 10^{-3} \, {}^{m^3}/_{min} = 6 \, {}^{l}/_{min}$$

The flow rate of $6 \, {}^{l}/_{min}$ is also achievable with almost all pump existing in the market. Thus, choice of pump will be based on provided outer pressure, flow rate, geometrical conditions, required power etc. Suggested pump is given in List of materials.

The performance curve for the pump is given in Figure 22. This chart shows that pressure for 0,06 *bar* can be achieved with the flow rate for 13 *l/min*. This increasing in flow rate will result in rising the water speed. However, values for velocity and pressure, assumed in the calculations, can vary during installation and pre-setting of the experimental loop. While the pressure in the pipeline less than 2 *bars* (this value is half of the maximum working pressure allowed for the Plexiglas pipes), it is possible to make adjustments in the flow and reach the suitable operating mode.

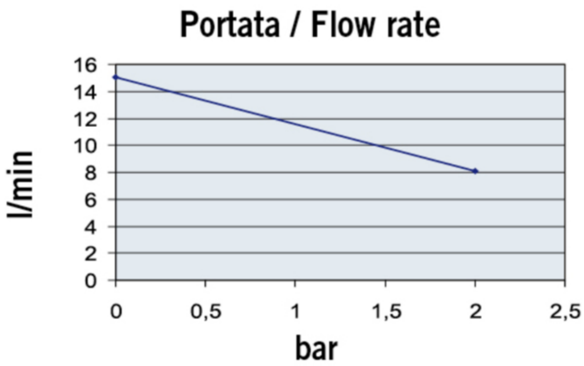


Figure 22 – Performance curve for the UP3/P pump. *(40)*

As for the previous suggested components, the pump can be changed for other models with the similar performance characteristics.

5.5.4 List of materials

Materials, required for launching and receiving stations are given in Table 7. The detail description of some components is listed in Table 8. Parts should be produced following the drawing, given in Appendix 1.

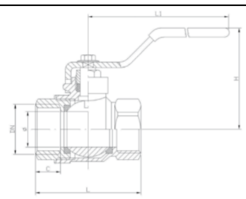
Table 7 – List of required materials.

Inner pipe	Total: 500 *mm* *Pipe ID=24 mm, OD=30 mm nominal diameter 1 section for 1 m*
Outer pipe	Total: 300 *mm* *Pipe ID=30 mm, OD=38 mm nominal diameter 1 section for 1 m*

O-ring	*Amount: 4*
Pump	*Water pump* *Amount: 1*
Valve	Solid ball valve *Amount: 6*
90^0 tee	PVC connection tee *Amount: 3*

As it was written before, connections to the pump and water supply tank are not significantly important

Table 8 – Description of components.

	Ball valve	**O-ring seal**	**Pump**	**90^0 tee**
Picture				
Material	Brass	Elastomer	-	PVC
Dimen-sions	$\emptyset = 25\ mm,$ $L = 71\ mm,$ $L = 128\ mm,$ $H = 65\ mm,$ $C = 16\ mm$	Width=1,78 *mm*	159x166x101 *mm*	-
Outer di-ameter (mm)	-	-	-	36 *mm*
Inner diam-eter (mm)	24 *mm*	25,12 *mm*	0.093 *kg*	30 *mm*
Mass/lengh (kg/m) or Mass (kg)	0,5 *kg*	-	1,5 kg	-
Pressure	-	-	2 *bar*	10 *bar*
Flow rate	-	-	15 *l/min*	-
Self-prim-ing	-	-	1,5 *m*	-
Production company (example)	Reference (41)	Reference (42)	Reference (43)	Reference (44)

for the experimental loop functionality and can be changed, as long as a layout is kept the same.

5.6 Design of installation

5.6.1 Requirements and constrains

Installation for the pipeline component should be designed for durable and secure fastening of the experimental loop, provide required orientation and placing of the loop in the workshop. Current design of loop is aimed to be hanged on a vertical stand and installation will be design for this purposes. List of requirements and constrains is given in Table 2.

To fix the loop of vertical surface it should be connected with several circular pipe holders. Type of the holders will ne given in List of materials.

Current design will imply that experimental loop is hanging on the vertical stand on the pipe support. However, its location can be changed for the wall, where respective connection for the pipe holders will be installed.

5.6.2 3D model

The 3D design of the installation stand with the support rings is given in Figure 23.

Figure 23 – Design of installation.

5.6.3 Analysis

It is important to know that the installation will support the weight of the experimental loop. To confirm this some calculations should be done.

The stress, appears in the pipe holders should be less that the yield stress for the material. The stress can be found by the following equation:

$\sigma = \frac{F}{A}$,

Where $F = mg$-gravity force, N

m – weight of the experimental loop, kg

A – cross-section of the pipe holder, m^2

Information about weight and cross sections can be taken from 3D model.

$m = 20\ kg$

$A = 66\ mm^2$

Substituting these values for the equation will give force of:

$F = mg = 20\ kg * 9{,}81\ {}^{m}/_{s^2}$ =196,2 N

Stress, appeared in one holder will be equal to:

$\sigma = \frac{196{,}2\ N}{66\ mm^2} = 3\ MPa.$

The yield stress for steel used for the holder is app. 200 MPa. From this calculation it is possible to make a conclusion that the structure will be safe even with one holder. Designed loop is placed by use of 10 holders that without doubts will provide durable installation.

5.6.4 List of materials

Experimental loop should hang on the pipe holders. This holders can be connected to the installation given about or to the wall, if the special connection of maintained on it. Description of this connection is given in Table 9.

Table 9 – Holder for pipe.

Holder	
Type	Sanitary pipe-fitting
Material	Stainless steel
Inner diameter	25 mm
Production company (example)	(45)

5.7 Interface

This chapter will include general information about the connections and interface layout. It is necessary to create a connection between Pig plug instrumentation and PC. As it was written before, one of the ways it to use WiFi module. However, there are other options like Bluetooth, GSM etc. Method of the signal transfer will be chosen during design of the electrical components.

Signal, received by the PC, contains the information about GPS position and result from vibration sensor. Moreover, the interface should provide information about amount of routes, made by pig plug, direction of the movement. Design of the layout can be modified in future, if some extra information will be added.

5.7.1 Interface layout

Suggested interface layout is given in Figure 24.

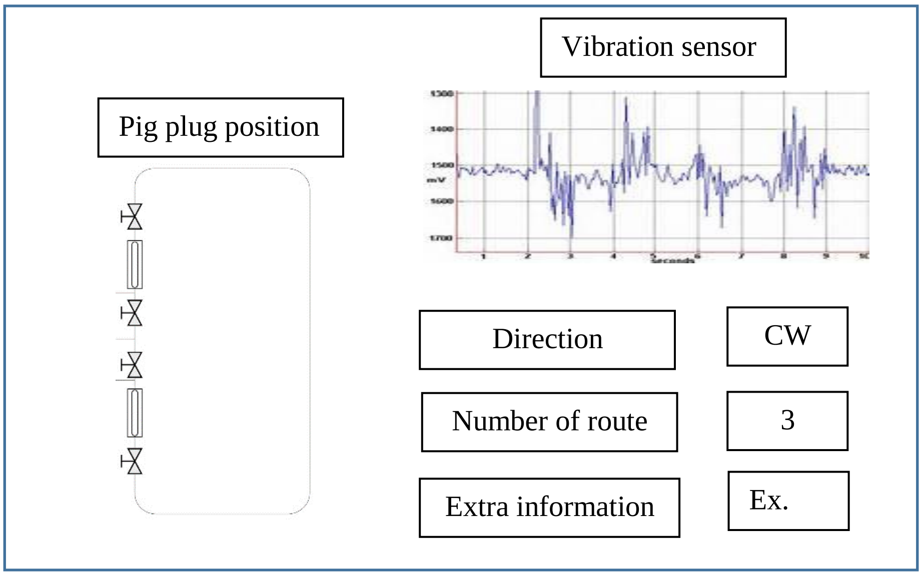


Figure 24 – Interface layout.

6 Operation

This chapter will show the operating mode for the experimental loop. The final design of loop is given in Figure 25. As it was written before, pig plug can travel through the pipeline in two directions; clockwise and counter clockwise. Setting of the pig plug in the experimental loop will be explained further in the chapter.

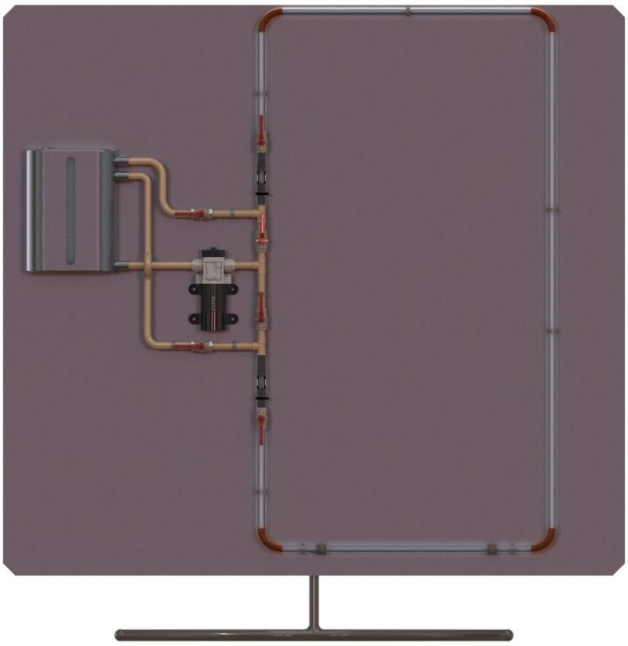


Figure 25 – Design of experimental loop.

Counter clockwise

The procedure of installing pig plug inside the pipeline and start its movement in clockwise direction is given in Appendix 2.

Clockwise

Clockwise direction working procedure is identical to the clockwise direction and given in Appendix 3.

Conclusion

This thesis was aimed to design an experimental loop to demonstrate pigging activity for the students in UiT Campus in Narvik. To reach this goal an extensive literature overview about pig plugs and pigging activity have been done. The study of different plugs, pipeline, pigging unit was done. Principals of positioning tracking, different methods of corrosion and roughness measurements were investigated.

Second part of the thesis uses the theoretical background to combine it with design process and develop a design of experimental loop. Final test stand have a lot of parts for purchase, other parts are easy to manufacture, assembly of it can be performed by use of UiT facilities. List of required materials is prepared for each pipeline component. Characteristics of valves and pump is also given in the thesis. The pig plug can perform some extra functions like GPS tracking and collecting information about inner surface of the pipeline. Ideas about connection between pig plug and PC and desired layout can be found in the final chapter of the thesis.

Future work

Further work on the experimental loop will cover the development of connection between pig plug and PC, programming of the MCU in the measuring module and creating the interface for PC, where students can read all necessary information. Moreover, the pipeline can be improved with different additional features like pressure measure, flow velocity measure, other type of pig plugs can be used for the pipeline. The set of exchangeable pipes for lower level of pipeline can be designed to demonstrate other types of collecting information.

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