Høgskulen på Vestlandet

MAS352 - Bacheloroppgave

MAS352

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Ja1

Autonomous Aviation Refuelling System

“The Game Changer”

NOUR ALNASHED

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KARINA VIKSUND

Bachelor’s thesis in mechanical engineering

HAUGESUND, Norway 2022

Høgskulen
på Vestlandet

Autonomous Aviation Refuelling System
“The Game Changer”

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Preface

This thesis is written at the Department of Mechanical and Marine Engineering (IMM) at Western University of Applied Sciences (WNUAS) as a completion of our bachelor's degree in Mechanical Engineering in Haugesund. The objective of the thesis was given by Imenco as a project to fully develop a prototype for Imenco's new patented design of a game-changing solution in aviation refuelling. The thesis was written during the spring of 2022 in collaboration with the aviation department at Imenco.

We would like to express our gratitude to *CEO* Rune Bringedal at Imenco for giving us the opportunity to be a part of developing this new and innovative solution. Additionally, we want to give a special thanks to *Head of Aviation* Andreas Knutsen at Imenco for his guidance as our supervisor, as well as providing us with all necessary technical data and relevant expertise. The patience and help we have received throughout this project is highly appreciated by the whole group.

We also want to thank our supervisor Liina Sangolt at Høgskulen på Vestlandet (HVL) for being available and providing us with valuable advice and feedback during frequent meetings and dialogues throughout the semester. These inputs and perspectives have been very helpful and motivating for us.

Many people have helped us along the way and provided us with valuable information and answers to many questions in all the different phases of the project. We would like to thank these competent people for their expertise and kindness to let them know that we are grateful for their assistance throughout the project of our thesis. This specially applies to the following people at Imenco:

Prabu Ravi and Daniel Johnsen – Automation department
Geir Osmundsen and Frank Lie – Mechanics
Ross Edmonds – Aviation Sales Manager
Michal Holody – Project Engineer
Jan Erik Hustvedt – Aftermarket Manager

Abstract

This project was given by Imenco with the aim of further development and design of a game-changing solution in aviation refuelling for onshore and offshore installations. “The Game Changer” is a system based on Imenco’s patented new way of refuelling with the purpose of removing the requirement of pumps by using pressurized nitrogen to move the fuel. This will allow the system to be remarkably reduced in size, making it both space and cost saving. The well-established aviation refuelling systems used in the offshore industry today require daily maintenance and manual sampling of the fuel by trained offshore personnel. This innovative aviation refuelling system is fully automated and remotely operated with the aim of automatic fuel sampling and testing within the compact design. By using well known technology along with solenoids, sensors and transmitters, the system is able to perform fuel quality checks and system test runs without the presence of any personnel. This will potentially improve the safety and fuel quality testing by reducing the risk of human error in manual testing.

The engineering design process used in this project is a highly iterative way of prototype development. This thesis will go into detail on all aspects of acting as project managers throughout the entire design process. A detailed project plan was established at the very beginning in order for the people involved to follow the progress and stay within the set time frame. The finished prototype is based on the calculations, piping and instrumentation diagram (P&ID), functional description, bill of materials (BOM), 3D-models, and production drawings that are presented in this thesis. These are all necessary documents for the mechanics and automation department at Imenco to build a fully operational prototype for testing.

There are several standards with rules and regulations that had to be taken into account, such as the requirement of the system being based on the latest edition of CAP 437 standards for helicopter landing areas. It was made clear that a dispensation must be applied from these strict regulations in order to test the system offshore. The task was limited to only the refuelling system itself and not the dispenser unit. The methods used throughout the design process will be described in this thesis, including the working principle and final design of the prototype, along with results from the prototype test runs.

In the early stages of prototyping, focus on functionality is a priority rather than the design aesthetics. The final design did not end up as compact as planned, with several adjustments and changes that were made by the mechanics during assembly of the prototype due to limited time, procurement, economic aspects, and other practical reasons. Because of delays in the assembly of the prototype, the planned testing also got delayed. This resulted in less comprehensive test runs than initially desired. The testing carried out in Imenco’s workshop with test runs of both refuelling mode and sampling mode. Both of these modes worked well during the testing, with several discoveries of potential improvements. The results were consistent with the process calculations that were made in earlier stages.

The results from the prototype testing shows that the principle of using nitrogen instead of pumps to move the fuel is entirely possible. The system proved to work as intended, removing the requirements of large skids and pump units with manual fuel sampling and testing. This is beneficial for the industry in both space and cost saving and could potentially change the way of aviation refuelling. It also has the potential to reach out to a bigger market by easily adapting to any market where fluid or gas needs to be moved.

Sammendrag

Denne oppgaven ble gitt av Imenco med et mål om å videreutvikle og designe en helt ny løsning for fylling av helikopter på onshore og offshore installasjoner. «The Game Changer» er et system basert på Imencos patenterte nye metode for fylling av helikopter som vil fjerne behovet for pumper, ved å bruke nitrogen til å levere drivstoffet. Dette vil gjøre systemet merkbart redusert i størrelse, som vil være både plass- og kostbesparende. De tradisjonelle og veletablerte systemene for fylling av helikopter i dagens offshore-industri krever daglig tilsyn og vedlikehold, med manuell prøvetaking av drivstoffet utført av kvalifisert offshore personell. Imencos innovative kompakte fyllesystem er fult automatisert og fjernstyrt for å gjøre all prøvetaking automatisk i selve systemet. Ved å ta i bruk kjent teknologi med solenoidventiler, sensorer og transmittere, kan systemet utføre prøvetaking for kvalitetssjekk av drivstoffet og kjøre rutiner i systemet uten behovet for personell til stede. Dette vil potensielt øke sikkerheten og forbedre kvaliteten på prøvetakingen ved å redusere risiko for menneskelige error.

Metoden for designprosess som er brukt i dette prosjektet er en høyst iterativ metode for utvikling av prototyper. Denne rapporten vil gå i detalj på alle aspektene som inngår i å fungere som prosjektledere gjennom hele designprosessen. I oppstarten ble det etablert en detaljert prosjektplan slik at alle personer involvert i prosjektet kan følge prosessen og tidsrammene. Den ferdige prototypen er basert på kalkulasjoner, flytskjema, funksjonsbeskrivelse, stykklister, 3D-modeller og produksjonstegninger som blir presentert i denne rapporten. Alle disse er nødvendige dokumenter for at mekanikere og automasjonsavdelingen hos Imenco skal kunne bygge ent fullt operativ prototype for testing.

Det finnes flere standarder for regler og lovverk som det må tas hensyn til, eksempelvis kravet om at systemet må baseres på siste utgave av CAP 437 «standard for helicopter landing areas». Det ble gjort klart at det må søkes om dispensasjon fra regelverket for å kunne teste produktet offshore. Oppgaven er begrenset til å kun gjelde selve fyllesystemet og dermed ikke inkludere leveringssystemet. Metodene som ble brukt gjennom hele designprosessen blir beskrevet i denne rapporten, som inkluderer arbeidsprinsippet og sluttresultatet av prototypen, i tillegg til resultater fra testingen.

I tidlig-fasen av prototyping vil fokuset ligge på systemets funksjonalitet og ikke det estetiske. Det ferdige designet av prototypen ble ikke like kompakt som det først var tenkt, og flere endringer og justeringer ble gjort underveis i byggingen av mekanikerne. Dette var på grunn av begrenset tid, bestillinger, økonomiske aspekter og andre praktiske grunner. På grunn av forsinkelser i byggingen av prototypen ble også testingen noe forsinket. Dette resulterte i en mindre omfattende test enn ønskelig. Testingen ble utført i verkstedet til Imenco, hvor både fylling og prøvetaking med testkjøring gjennom systemet ble utført. Begge disse viste deg å fungere ganske bra under testing, og det ble avdekket flere muligheter til forbedringer. Resultantene fra testingen var konsistente med prosesskalkulasjonene som ble gjort tidligere i prosjektet.

Resultatene fra testingen av prototypen kan konkluderes med at prinsippet om å bruk nitrogen i stedet for pumper for å levere drivstoffet er bevist. Systemet fungerte som det skulle, og fjerner dermed behovet for store skids og pumpeenheter med manuell prøvetaking. Dette kan være gunstig for industrien ettersom pumper er plasskrevende og består av mange deler som må skiftes ut ved jevne mellomrom. Fyllesystemet har også potensiale til å nå ut til et større marked ved å tilpasses til et hvert marked hvor fluider eller gass trenger å flyttes.

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Nomenclature

A = area [m^2]

D_i = inlet diameter [m]

L = pipeline lenght [m]

M = molar mass [kg/kmol]

P = pressure [kg/m^2]

Q = flow rate [m^3/s]

R = gas constant [J/mol*K]

Re = Reynolds number [-]

T = absolute temperature [K]

V = volume [m^3]

V = velocity [m/s]

Z = compressibility factor [-]

e = pipe roughness [mm]

f = friction factor [-]

h = height [m]

h_L = head loss [m]

h_{major} = major loss [m]

h_{minor} = minor loss [m]

m = mass of a substance [kg]

$\dot{m}$ = mass flow rate [kg/s]

n = number of moles [kmol]

Δp_{total} = total pressure drop [bar]

ζ = minor loss coefficient [-]

μ = dynamics viscosity [Pa*s]

ν = kinematic viscosity [m2/s]

ρ = density [kg/m^3]

1. Introduction

This section will provide background information for the project and give an introduction to the project's aim and objectives along with limitations. The introduction will focus on Imenco's vision for changing the way of aviation refuelling and present the scope of work that goes into this thesis.

1.1 Background

Aviation refuelling has always been slow to adapt new technologies, using outdated mechanical components. Imenco is an innovative and forward-thinking engineering company with more than 30 years of experience in delivering and maintaining aviation refuelling systems. They are one of the leading companies in this field and has set the standard for high quality, cost efficient and customer orientated aviation fuelling systems.

Traditional fuelling systems consist of large skids that require a lot of space with pump units and storage tanks with drip trays, along with recycle and sample units with tanks, pumps, motors, valves, and sensors. Large fuelling systems contain great amounts of components and moving parts that are often subjected to wear and tear and must therefore be replaced or repaired more frequently. The consequence of this is an increase in maintenance costs from purchasing new parts along with higher expenses for working hours. Moving parts that needs to be replaced frequently also have a negative impact on the environment. Reducing the amount of components and moving parts will likely expand the lifespan of a product in addition to lower the cost of production, installation, and maintenance. Another beneficial aspect of developing a more compact system is the simplifying of assembly and installation process. This will make the end product more appealing to the market and potential clients.

Aviation fuelling systems require daily maintenance and manual testing of fuel quality by trained personnel to meet offshore standards and regulations. Helicopter fuelling on the Norwegian continental shelf is regulated by the Civil Aviation Authority of Norway (CAA Norway). This is an autonomous and independent administrative body responsible for ensuring safe and efficient operation of civil aviation in Norway. CAA Norway issues regulations in the field of aviation. Correct handling and monitoring of jet fuel quality is crucial to prevent errors that may ultimately result in aircraft malfunction with fatal consequences. Strict requirements are set for performing inspections and routines for handling fuel and equipment.

Imenco wants to challenge the established solution for aviation refuelling by using known technology to increase safety and fuel quality with a fully automated system that does not require physical supervision on a daily basis. A system like this will make it possible to share data from remote locations and reduce the workload of control and inspection. The strict regulations for helicopter refuelling makes it difficult to adapt the new solution to the oil and gas industry with the current rules.

1.2 Aim and objectives

The aim of this project is to further develop Imenco's design into a fully operational prototype ready for installation and testing. The Blackbox will remove the requirements of pumps by using nitrogen to move the fuel. Complete with all automated control valves and pipework, the system can perform automated daily, weekly, and monthly inspections. The technology is designed initially for the offshore marked but will easily be adaptable to any market where fluid or gases are needed to be moved. This thesis will take into consideration engineering methods, manufacturing possibilities and procurement strategies to enable Imenco to not only deliver the latest technologies to market, but to do so with lower costs, better manufacturing methods and easier procurement strategies. The main function of this system is to deliver Jet A-1 fuel in a clean, water-free condition to Imenco's standard compact aviation refuelling dispenser unit. The system is based on the latest edition of CAP 437 "Standards for offshore helicopter landing areas" and may be used for refuelling almost all helicopter types.

To meet the requirements given by Imenco, the project is divided into the following objectives:

- Prepare a project plan to follow up the progress of the project
- Create a P&ID for the system including all the components and information needed
- Make a 3D-model assembly and GA drawings of the system
- Establish a Bill of Materials (BOM)
- Technical and functional description of the system
- Project management including building and testing of the prototype

1.3 Limitations

This project is limited to the development and design of the Blackbox and will only cover the process of moving fuel from the storage tank to the delivery system. The thesis will not include connected units such as gas bottles or Imenco's delivery system. Due to limited time the design and prototyping will not include the housing of the system and will only consist of an open system for testing.

- The development and design will only cover the process of moving fuel from the storage tank to the delivery system. This is limited to the Blackbox and its components only.
- The thesis will not include connected units such as gas bottles or dispenser unit.
- The design will not include the housing of the system due to limited time
- All electrical work and automation is done by Imenco and will not be included
- Assembly and installation will be done by Imenco
- Testing of the prototype will be performed and documented in collaboration with Imenco

2. Background theory

This section consists of a brief description of helicopter refuelling, and general theory and function of main components relevant to the project such as valves, filters, sensors, and transmitters. It will also include an introduction to nitrogen gas as dry air and jet fuel used for helicopters.

2.1 Helicopter refuelling systems

Today's offshore refuelling systems will generally be divided in two categories of "transportable tank systems" and "static storage tank systems". The elements of these systems are mostly the same, both consisting of transit tanks, a fuel delivery pumping system, and a dispensing system. In addition, the static storage tank system also includes static storage facilities, and a sample reclaim tank. The main function of these refuelling systems is to deliver jet fuel that is clean and free from water or other contaminants. Due to the scope of the project, this thesis will only go into detail on the transportable tank system in order to give a brief introduction to today's standards.

The transportable tank system typically consists of two transportable tanks, a laydown skid with pump unit and a standalone dispenser unit. Figure 2.1 shows Imenco's refuelling system. Because of the tank bottom outlet, it is required to have a drip tray that can hold 110% of the tank volume in case of any fuel leakage. The system is based on manual sampling for fuel quality control and require daily maintenance by offshore personnel. Today's helicopter refuelling systems are designed to meet the requirements of CAP 437 "Standards for offshore helicopter landing areas", which is described in Chapter 3.3 of this thesis. Sampling and testing of the fuel is required to ensure that the delivered fuel is of the highest quality and the fuel must be completely free from any water particulates or contamination. Impurities and water in jet fuel may ultimately lead to engine malfunction in the aircraft. The process of inspection, sampling, and testing of jet fuel is mainly done in field tests with visual appearance check and chemical water detection. All fuel samples should be drawn at full flow and must be taken directly from the lowest point in the fuel tank or filter vessel. Manual samples are drawn into a clear standard glass sample jar of 3 litre and is checked for any changes in colour by using a chemical water detector capsule. Fuel quality sampling and requirements for fuel sample containers are described in chapters 8.7-8.19 defined in the CAP 437 regulations.

Figure 2.1 – Imenco's offshore refuelling system

2.2 Jet A-1 fuel

Jet A-1 is an aviation fuel commonly used for helicopters and other turbine-engine aircraft. The kerosene grade fuel is produced to a standardized international specification and must meet the requirements of DEF STAN 91-91 (Jet A-1) [1] and ASTM D1655 (Jet A-1) [2]. The jet fuel is a combustible hydrocarbon liquid with a minimum flashpoint of 38°C and a maximum freezing point of -47°C. The detailed properties of this type of jet fuel is described in Attachment 1. Jet A-1 is still considered a relatively safe fuel, as it is less combustible compared to shorter hydrocarbon chains and is not designed to ignite in liquid form at temperatures lower than its flashpoint. Ignition sources in the offshore industry are carefully controlled, but movement of fuel through the system can cause electrostatic charges that may lead to ignition. As follows, it is important to design the system to prevent it from being exposed to ignition conditions in the vicinity of the fuel to the greatest possible extent. Figure 2.2 shows a transportable storage tank containing Jet A-1 fuel.

Figure 2.2 – Imenco’s trnasportabale jet fuel storage tank

2.3 Dry air / nitrogen

The most abundant gas in the Earth’s atmosphere and dry air is nitrogen [3]. Nitrogen is an inert dry gas that is both odourless and colourless. In the offshore industry nitrogen is commonly used for a variety of functions in drilling, processing, and completion of oil and gas wells. Nitrogen is also used for tank blanketing and to prevent flammable gases from igniting [4]. For industrial use, nitrogen is extracted from air by using a nitrogen generator, making the gas easily available at a lower cost.

Standard dry air is a mixture of the three major components nitrogen, oxygen, and argon. The volumetric composition of dry air is about 78% nitrogen, 21% oxygen, and 1% argon, amongst fractions of several trace gases. Most importantly, dry air needs to be clean and completely free of any water vapor. The purity of clean, dry air depends on the application in which it is used. In a process where pressurized gas is being used to move fuel through the system, it is important that the gas is completely dry to avoid any condensation in the tank or contamination of the fuel [5]. Moisture may cause rust and increased wear of components that could lead to improper function of the equipment and loss of performance efficiency. The dry property of nitrogen ensures that it does not condense in the tank and contaminate the fuel or cause any damage to the equipment and process. On the other hand, nitrogen is more expensive than dry air, therefore dry air would be preferred in systems that are used more frequently.

2.4 Filtration of fuel

Filtration is the process of mechanically removing harmful contaminants and impurities from fluids in a system. This is an important step to ensure both quality and safety of the process, and to protect equipment from any damage. Filtration plays a key role in aviation fuelling and is essential in order to deliver clean fuel that is free from impurities and water contaminants. The fuel should be filtered every time it is moved to remove any water, particulates, surfactants, or microbial growth [6]. Debris from microorganisms will plug the filters and may eventually lead to corrosion of the pipes. The filter vessel should be equipped to measure pressure drop across the filter to indicate any build-up in the filter cartridge. A certain pressure drop will indicate that the filter cartridge is dirty or fouled and must be replaced. The most commonly used filters in jet fuel filtration are two-stage filter water separators.

2.4.1 Filter water separator

Filter water separators are used to remove solids, particulates, and water contaminants from jet fuel and other hydrocarbons. The filter vessels are fitted with coalescer and separator elements that generate a two-stage separation process when high efficiency water removal is required [7]. These elements are illustrated in Figure 2.3. The first stage consists of coalescer elements that will remove particulates and coalesce small water droplets into larger droplets. These droplets will sink to the water sump of the filter vessel because they have a higher density than the fuel. Separator elements in the second stage will repel any remaining water droplets while letting the fuel pass through. The small droplets will gather on the surface of the element before sinking to the water sump. A sample line at the lower point of the filter vessel is required to ensure that the fuel is free from any contaminants.

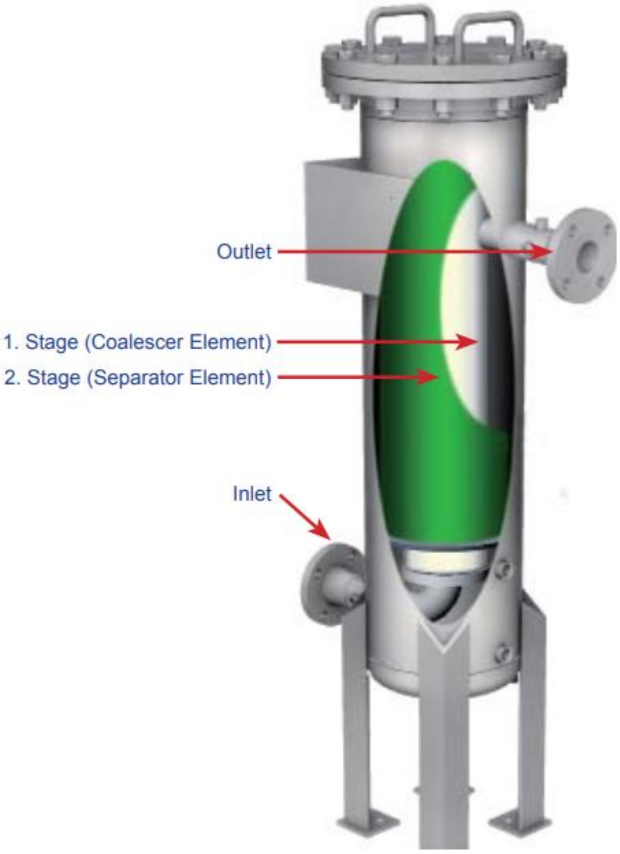


Figure 2.3 – Two-stage filter water separator

2.5 Valves

Valves are mechanical devices used in piping systems to control the flow and pressure within a system of process. Their main function is starting and stopping a flow, increase or reduce a flow, change the direction of a flow, or regulating the pressure of a process [8]. There are many different types of valves depending on what needs to be controlled and regulated. The most common types of valves used in process piping are gate valve, globe valve, check valve, plug valve, ball valve, butterfly valve, needle valve, and pressure relief valve [9]. These valves can also be classified by function and purpose, divided into the major categories of isolation, regulation, non-return, and special purpose. Valves can either be manually operated, or they can be automated by using pneumatic, hydraulic, or electric actuators.

2.5.1 Control valves

Control valves are power-operated devices used to regulate or maintain the flow rate, pressure, or temperature of a fluid. The control valve keeps the regulated process variable within a required operating range. This is done by fully or partially opening or closing the valve automatically by the use of pneumatic, hydraulic, or electrical actuators [10]. These actuators are shown in Figure 2.4. The control valve receives a signal from a controller that compares the process variable with the desired set point. The controller will then produce and output signal to move the valve. A control valve normally consists of a valve body, positioner, actuator, and accessories. This is the most common final control element in the industry and is a critical part of the process control loop.

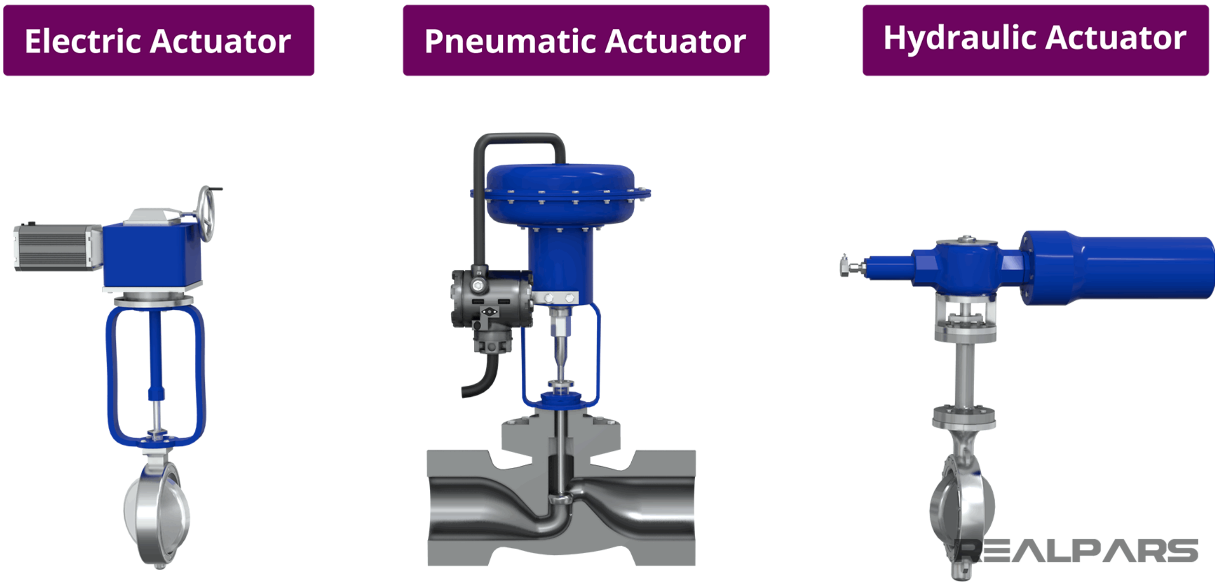


Figure 2.4 – Different actuators on control valves

2.5.2 Solenoid valves

Solenoid valves are commonly being used in systems where the fluid flow must be controlled automatically or remotely. This makes them useful in unmanned plants or automated systems where they can be controlled by electrical switches. A solenoid valve is electrically controlled with the aid of a solenoid actuator and is used for neutral, clean liquids and gases. In the automation of fluid and gas control it is extremely important that the liquid flows without any leaks. Solenoids are very fast acting valves that can open or close quickly. They are reliable, compact and require little power.

These valves are control units that help control the flow of a fluid through the system in a fully closed or fully open mode. Solenoids work as an electromagnet that can either shut off or allow fluid flow by electrically energizing or de-energizing the actuator [11]. When the normally closed solenoid valve is de-energized, the plunger is down and prevents any fluid flow. By energizing the electromagnetic solenoid coil, an electric current will run through the solenoid and lift the plunger to let the fluid pass. The major parts of a solenoid valve are illustrated in Figure 2.5.

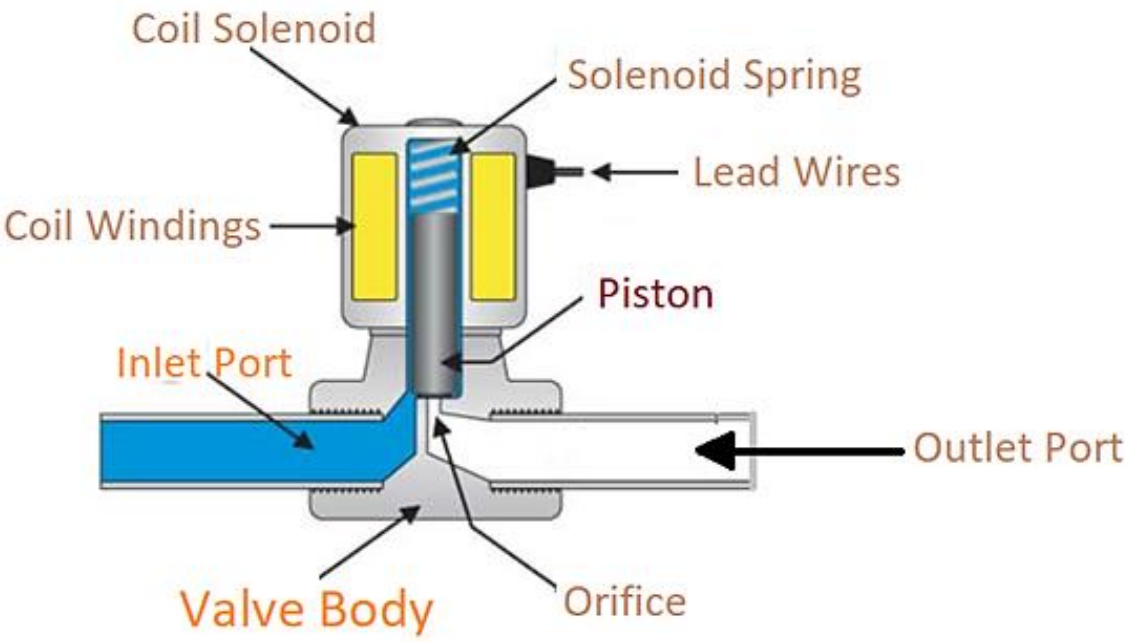


Figure 2.5 – The parts of a solenoid valve

2.6 Sensors

A sensor is an input device used for medium measurement by sensing and converting a physical property into a usable output. The working principle is illustrated in Figure 2.6. Sensors, or transducers, consist of a sensing element and a conversion element [12]. The sensing element detects information or changes in the environment, while the conversion element transforms this data into an electric signal. Different types of sensors can provide information about the instrumentation to help monitor and regulate the performance of a process. Sensors can be a particularly useful tool in systems where it is difficult to get direct access to an instrument for measuring. They can also be useful for controlling critical parameters in a system and must be calibrated in order to be reliable. The most common sensors used in process industry are pressure sensors, temperature sensors, level sensors and flow sensors [13]. Other types of sensor technologies are also used for detection of particulate matter and free water in jet fuel. These sensors can be used monitoring the fuel quality or checking if the filters absorb water properly.

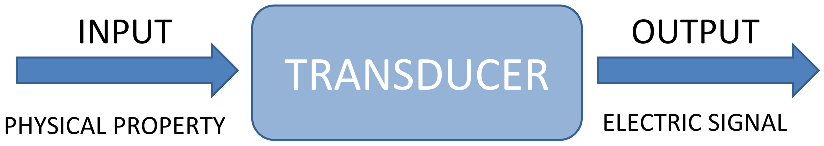


Figure 2.6 – Transducer input and output signal

2.7 Transmitters

Transmitters are electronic devices commonly used in process instrumentation for monitoring and control to ensure safety, stability, and reliability of any process or operation. The main function of a transmitter in process control is to receive signals from a connected or integrated sensor, then converting the input signal to an output signal. A transmitter generates an output signal that is proportional to the measured input signal. The output signal type from electric transmitters is usually current output or voltage output. There is a broad variety of transmitters depending on which parameter is to be measured. Transmitters are mainly used for providing accurate measures of variables such as pressure, temperature, level, and flow in a process.

2.7.1 Level transmitter

A level transmitter is an instrument that provides a continuous level measurement of a liquid or solid medium in a tank, vessel, or container. The transmitter generates an output signal which is transmitted to a control room for level display. There are many different types of level transmitters depending on their application. The most common technologies for level measurement are guided microwave, magnetic, capacitance, hydrostatic, ultrasonic, and radar level transmitter [14]. The main difference between the radar and ultrasonic instruments is the type of wave that is used. These two types of instruments are illustrated in Figure 2.7 Radar level transmitters use radio waves, while ultrasonic level transmitters use sound waves.

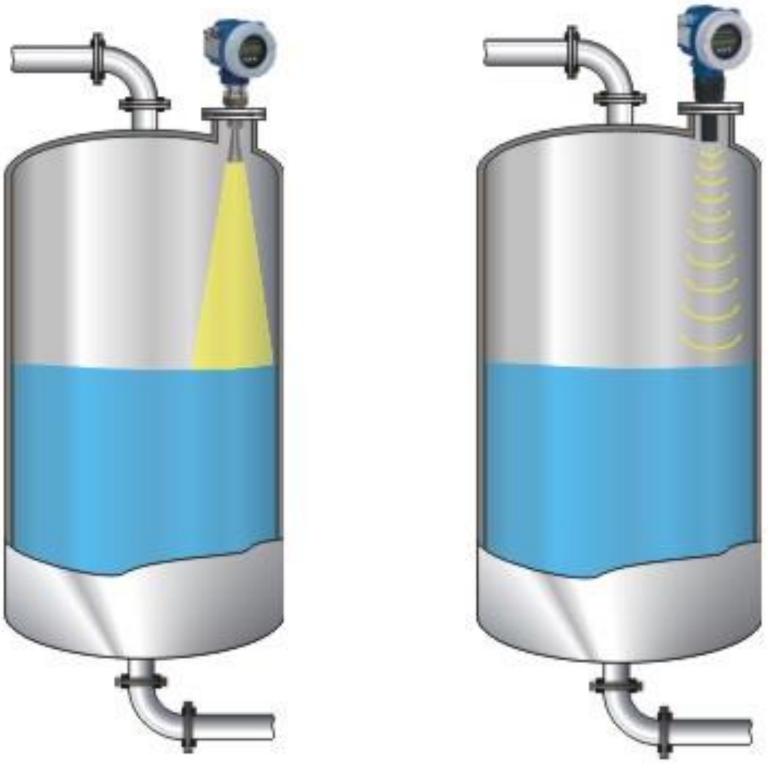


Figure 2.7 – Differencve between radar level transmitter and ultrasonic level transmitter

Radar level transmitters are usually mounted on top of the tank and is a non-contact level measuring device. High-frequency radar pulses are emitted by the antenna into the surface of the fluid. Some of the pulses are reflected from the surface and sends a signal back to the receiver built in the transmitter. The time taken by the transmitted signal to return is measured by an electronic circuit and is proportional to the distance travelled. The fluid level is then calculated from these variables with the known geometry of the tank and transmitted to a control room [15].

2.7.2 Pressure transmitter

A pressure transmitter is a device that measures the pressure of a liquid, fluid, or gas in a process. A transmitter converts the mechanical pressure into an electrical signal that is proportional to the applied pressure. The electrical output signal is then transmitted to a programmable logic controller (PLC) and displayed for pressure monitoring. The working principle of this conversion is illustrated in Figure 2.8. This is an important instrument in order to alert operators of either high-pressure or low-pressure levels to prevent any incident from occurring. The main purpose of a pressure transmitter is to measure a pressure range of either absolute, gauge, or differential pressure, depending on its application [16]. Although there are many different types of pressure transmitters, they generally consist of the same three components, a pressure sensor, a measuring circuit, and a process connection [17]. The advantages of pressure transmitters are their small size, durability, fast response, and high accuracy. They are extremely versatile and have a wide range of different uses.

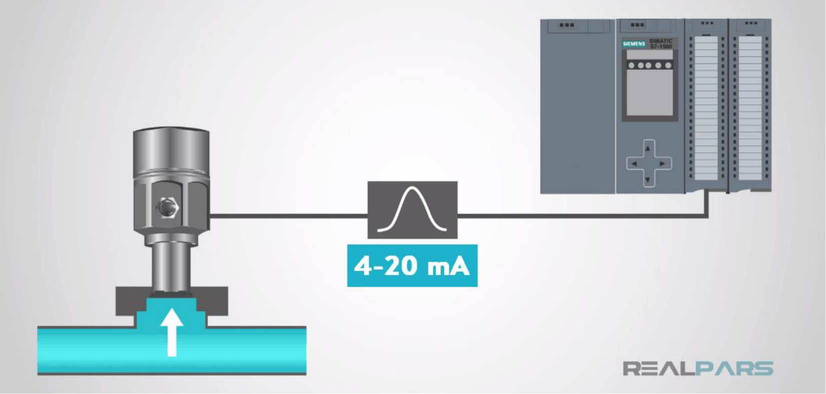


Figure 2.8 – Pressure transmitter

2.7.3 Differential pressure transmitter

A differential pressure transmitter is a device that measures the difference between two applied pressures. Their working principle is based on the difference between a measured pressure and a reference pressure. The transmitter will have two pressure ports labelled “high” and “low” which represents the different effects on the output signal. The measured pressure difference between these two ports is converted to an electric output signal with reference to a calibrated pressure range [18]. The output signal is then transmitted to a remote process control instrument. Differential pressure transmitters consist of a primary element, a secondary element, and electronics housing [19]. These are shown in Figure 2.9. The secondary element measures the differential pressure produced by the primary element as accurately as possible.

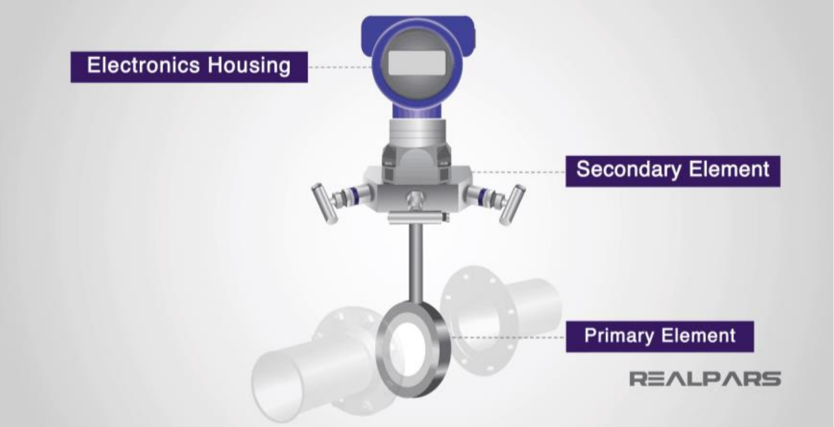


Figure 2.9 – Parts of a PDT

Differential pressure transmitters are very versatile and is the most useful industrial pressure measuring instrument. The most common application for differential pressure transmitters is flow rate measurement, but it can also be used for level measurement, or filter and pump monitoring. By creating a pressure drop across the filter, it is possible to determine if the filter is clogged or needs to be replaced.

3. Method

This chapter is divided into sections consisting of a theoretical approach on how the problem is solved, choice of methods, equations, requirements, and design criteria. These are all important elements in the initial phase of the project which lays the groundwork for any further work. The approach and different methods used in this project are described step by step in the next sections, followed by a detailed presentation of the design process including procedures for prototyping and testing of the system.

3.1 Theoretical approach

The main objective of this project is to further develop and design a prototype of Imenco’s compact aviation refuelling system for offshore helicopters. A lot of work goes into the process of design development, prototyping and testing. When acting as project manager throughout an entire design process, there are several aspects to take into consideration in order to maintain control of the progress. Several methods are used in approaching the problem to define a functional solution, and the engineering design process is a method typically used for these types of projects [20]. This is an iterative process where multiple steps are repeated throughout the project to make improvements along the way. The common steps in the engineering design process are illustrated in Figure 3.1. This model is useful for any design process, although the different steps illustrated may vary depending on the project.

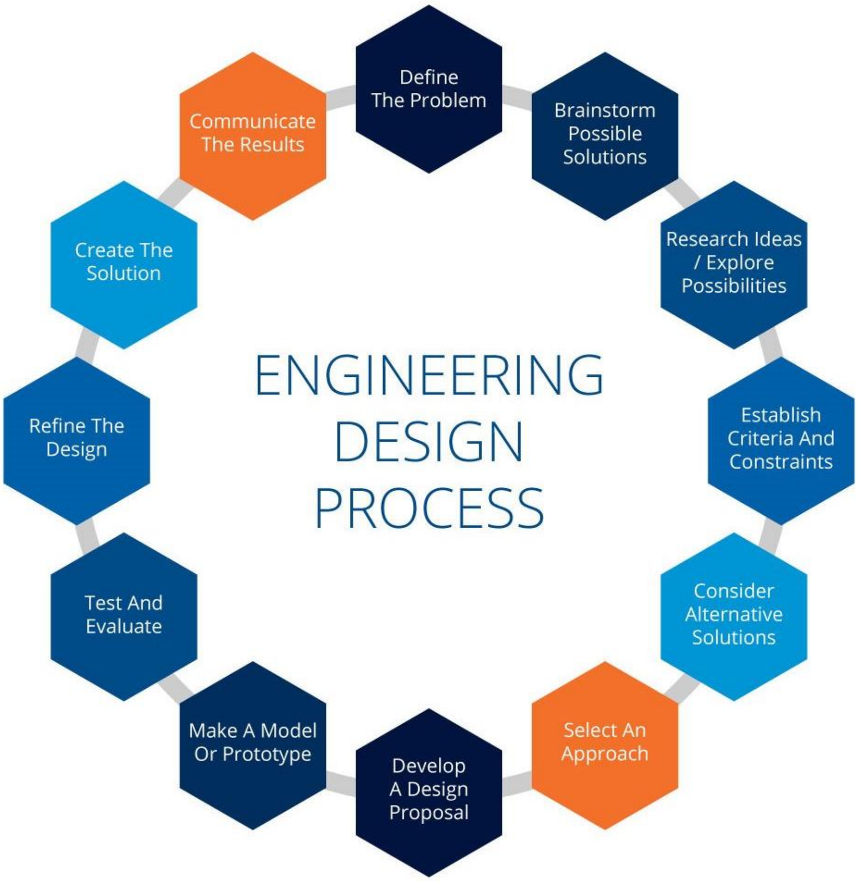


Figure 3.1 – Engineering design processs

The first and most important step in approaching "The Game Changer" project, is to establish a project plan with the scope of work organized, including all the start-up and finishing dates for the various stages of the project Attachment 2. The project plan is updated along the way to keep track of the progress and make changes according to any delays or work that is completed ahead of schedule. This is an important element in order to make sure that everything is done properly and according to plan. As engineers working with many different people, it is essential that everything is documented along the way. The main phases of the project plan and design process is based on design review, drawings, procurement, production, assembly, and testing. In the initial phase of the project, frequent meetings with the people involved are essential to define the problem and figure out how to approach the task. Thorough groundwork is important to keep a solid structure throughout the process. When all the objectives are defined and the overall design is reviewed, the project is ready to move on to the following stages of the project plan.

The next step is to produce all the necessary documents and drawings needed for the production phase. This involves creating a piping and instrumentation diagram (P&ID) of the system. Establishing a P&ID is an essential step in any engineering design process. This is a schematic illustration of how the piping, instrumentation, and related components are interconnected and their function in a process flow. The purpose of a P&ID is to get a graphic representation of the process, and to provide a basis for further development of the system in the following design stages. The symbols used in a P&ID may vary depending on who is making the diagram. Therefore, it is important to prepare a symbols legend sheet that describes each of the symbols being used. The P&ID is reviewed several times where many changes are made until it reaches a desired outcome for the system.

When the final P&ID is reviewed and approved, a general bill of materials (BOM) is established to get an overview of which components and parts that needs to be procured. The bill of materials is a complete list of all the components and materials required to manufacture a product. Some items may have an extended delivery time depending on availability. Therefore, it is important to create a basic BOM early on in the project, so that all the parts ordered will arrive within the timeframe. To know what type of components and materials to use in the system, different calculations of pressure, flow and velocity are made for every component as well as the whole system. The data from this procedure contains crucial information in order to evaluate pipe diameter and fittings, choose the right valves, filters, and every other component with the correct properties to meet the system's criteria. A functional description is then made from the combination of the P&ID, calculations, design criteria, and BOM. This is a comprehensive document that specifies how the process will function and what the control system should do in each operation. The functional description defines the process automation requirements and is used to program the control system.

The final stages of the design process is to build an operational prototype of the system and run tests on the model. Prototyping is an essential step in the process of product development in mechanical engineering. Designing and building a prototype is very useful for physical realization of a concept into an operational model in order to run tests and evaluate the product's performance and functions. Prototyping is an iterative process in which several changes and improvements are made throughout the process in order to optimise the performance and design of the final product. The prototype is then tested in order to analyse the function of the assembly and evaluate what changes and improvements need to be done for further development [21].

3.2 Design criteria

Imenco have provided several requirements and specifications for the design and function of the aviation refuelling system which is defined in a request for quotation (RFQ) found in Attachment 3. The system is designed with the aim of removing the requirements of pumps by using dry air or nitrogen to move the fuel, and will eventually be connected to Imenco's standard compact dispenser unit to deliver Jet A-1 fuel in a clean, water-free condition at a flow rate of 13.5 m^3/hr. This system will be based on standards from the Civil Aviation Publication for offshore helicopter landing areas (CAP 437) latest edition in order to be suitable for refuelling of almost every helicopter types. To make the system as compact as possible, it will be mounted directly on the manway opening of the jet fuel storage tank and should not protrude past the tank's frame. The material of construction should be 316L stainless steel and Viton seal material.

The general design should meet the criteria provided by Imenco, although some alterations may occur during the design process due to practical reasons. The most critical requirements include a flow rate of 225 litre per minute and a maximum available working pressure (MAWP) of 8 bar. In addition, the system should be able to sustain a test pressure of 10 bar. Certain instrumentation is required to be included in the system that will consist of 1off tank level transmitter, 1off pressure transmitter, 2off differential pressure gauges, 2off filter water separators and 1off AFGUARD fuel quality sensor. The filters shall be fitted with a low point drain and differential pressure transmitters. Other instrumentation should be included such as pressure relief valve in accordance with ASME specifications, document controller and bonding between the tank and frame. This instrumentation have to meet the criteria of the required safety ratings and approvals for the specific component. The refuelling system should be fitted with a stainless-steel flange connected to the unit outlet, and a female dry break coupling on the other end. The aim is for the system to be complete with all automated solenoid valves and pipework in order to perform automated daily, weekly, and monthly inspections without the requirement of physical supervision and sampling by offshore personnel.

3.3 Rules and regulations

There are several strict standards and quality requirements that must be followed in designing a system suitable for offshore helicopters. These standards are necessary in order to ensure the highest quality of aviation fuel delivered to helicopters from offshore installations and vessels. Under no circumstances should the fuel be exposed to contamination such as particulate matter or free water. The quality requirements are essential in order to have safe operation of the systems at all times. In the process of designing the refuelling system it is important that the required standards are given proper consideration to prevent any contamination, malfunction, or fuel leakage in the system. The following sections will describe some of the most important standards of rules and regulations relevant for this project.

CAP 437
The CAP 437 "Standards for offshore helicopter landing areas" [22] provides guidance on the criteria required by The Civil Aviation Authority (CAA). The publication is internationally recognized as a representation of minimum standards for the safe operation of helicopter to offshore helidecks world-wide. CAP 437 is an important standard for offshore helicopter landing areas that contains the most prominent requirements necessary for fuelling of helicopters on offshore installations and vessels. Chapter 7 and 8 of CAP 437 defines the standards and requirements for helicopter fuelling facilities with relevant content from CAP 748 on aircraft fuelling and fuel installation equipment [23]. The system's design and construction requirements for helicopter fuelling systems are described in chapter 7 as a guidance to the standards and improvement of existing offshore installations. Chapter 8 provides a general guidance to maintenance and recommended fuelling procedures of helicopters on offshore installations. Authorized companies are required to inspect new designs of refuelling systems to ensure that they meet the requirements of the standards given.

NORSOK standards
The NORSOK standards are a set of strict rules, regulations, and policies developed by the Norwegian petroleum industry [24]. These standards are designed to ensure safety, cost effectiveness, and improve competitiveness for petroleum industry development and operations on the Norwegian continental shelf. The functional requirements in the NORSOK standard C-004 [25] defines the basic requirements for design, arrangement, and engineering of helicopter decks on offshore installations. This also includes fixed type installations, unmanned installations, floating installations, production, drilling, and storage vessels.

074 – Recommended guidelines for helideck manual

The Norwegian Oil and Gas Association guideline 074 [26] provides the recommended guidelines for helideck manual to ensure uniform practice for work, landing and take-off operations on the helideck. They also specify responsibilities and requirements for helideck crew and equipment used in petroleum operations on the Norwegian continental shelf (NCS) [27]. Chapter 6 of the recommended guidelines provide general information on aviation fuel handling and minimum requirements for using equipment in helicopter fuelling operations. Additionally, Appendix J provides the specifications for offshore refuelling systems applicable for all fixed and floating installations operating on the NCS.

Standards for fuel quality, sampling, and testing

The Joint Inspection Group (JIG) is a world-leading organization for aviation refuelling system standards [28]. The JIG standards include recommended practice for fuel sampling and testing, with internationally agreed upon procedures to ensure that aviation fuel is transported and stored safely. These standards are supported and approved by The International Air Transport Association (IATA), which is an organization that provides expertise in assessment of fuel quality and fuel delivery, along with practices for maintenance for fuel filters [29]. The IATA Fuel Quality Pool (IFQP) share fuel inspection reports at locations worldwide [30]. The Energy Institute (EI) Aviation Fuel Handling Standards provide specifications for fuel handling and fuel quality to ensure delivery of clean jet fuel to aircrafts. The EI publications for qualification procedures are applicable to filter water separators, fuel filter elements, and fuel sensing devices that handle aviation fuel such as Jet A-1 [31, 32].

3.4 Formulas

This chapter describes all the relevant formulas that are used in developing the refuelling system. These calculations are essential in order to meet the given criteria in designing the prototype. It is important that the dimensioning is done properly to ensure that the fuel is delivered safely, and for the system to be able to withstand the forces it is subjected to [33]. Additionally, these calculations are crucial for selecting the right components and necessary parts. The following sections will present the methods used in dimensioning the fuel pipes, and for calculations of gas and pressure drop in the system.

Dimensioning of pipes:

When dimensioning pipelines, the two most important parameters are fluid velocity and pressure drop in the pipeline. These parameters can be found by using the law of continuity and Bernoulli's equation. The average fluid velocity, V, is related to the flow rate and is given by:

$$V[m/s] = \frac{Q[m^3/s]}{A\ [m^2]} \tag{1}$$

Where Q is the volume flow rate, and A is the cross-sectional area of the flow. Liquids like fuel are considered an incompressible fluid. The law of mass conservation, states that the mass flow rate of a fluid through a pipeline system is constant [34], and is given by the equation of continuity:

$$\dot{m}\ [kg/s] = Q\ [m^3/s] * \ \rho\ [kg/m^3] = constant \tag{2}$$

The mass flow rate, $\dot{m}$, in a system is related to the volume flow rate and fluid density, ρ. For incompressible fluids the density remains constant. Common applications for the continuity equation are pipes or tubes with flowing fluids [35]. Nominal diameter values are standardized and are used in selecting pipes and connection fittings. The main pipe dimensions are outer or inner diameter and wall thickness. The pipeline diameter depends on the purpose and area of application, such as the fluid medium, pressure, and flow capacity. To find the necessary diameter of the pipeline, the following formula is used:

$$D_i[m] = \frac{Q[m^3/s]}{V[m/s]} \tag{3}$$

Where D_i is the inner diameter of the pipeline. It is crucial that the pipes are able to maintain the requirement for volume flow and velocity. An increase in pipe diameter will result in an increase of flow rate. Likewise, a decrease in pipe diameter will reduce the flow rate.

Nitrogen gas calculation:

The ideal gas law is a mathematical equation used to solve problems related to gases. The most important variables associated with the ideal gas law are volume, temperature, and pressure of the gas. The ideal gas law is expressed in two approximate formulas that represent the gas in different ways. The difference between a real gas and an ideal gas is that a real gas is a gaseous compound that already exists. An ideal gas is a gaseous compound that does not exist in reality but is a hypothetical gas. However, some gaseous compounds exhibit behaviour almost similar to that of ideal gases at specific temperature and pressure conditions, where the concept of ideal gas was created because it is difficult to describe real gas exactly. It is merely an approximation that helps predict and understand the behaviour of real gases through laws that follow the ideal gas.

Ideal gas equation of state in terms of moles:

$$P\mathrm{V} = nRT \tag{4}$$

Whereas the real gas defined as:

$$P\mathrm{V} = nZRT \tag{5}$$

The ideal gas law relates the absolute pressure, $P(Pa)$, and volume, $\mathrm{V}(m^3)$, of the gas to the number of moles, n, and the temperature, $T(\mathrm{K})$, of the gas [36]. R is the universal gas constant of 8.3145(*J/mol*K). The real gas law also includes the compressibility factor, Z. The compressibility factor of gases, also known as the pressure factor or gas deflection factor, is a correctional factor that describes the deviation of a real gas from the behaviour of an ideal gas [37]. In thermodynamic, the compressibility factor is simply defined as the ratio of the molar volume of an actual gas, to the molar volume of an ideal gas at the same temperature and pressure. The compressibility of a gas depends on the particular gas as well as temperature and pressure conditions. This is a useful thermodynamic property for modifying the ideal gas law to account for the behaviour of a real gas. In general, the deviation from ideal behaviour becomes more significant as the gas approaches a phase change, the lower the temperature or the higher the pressure. In order to calculate the amount of nitrogen gas, $m(kg)$, the following equation is used:

$$m = \frac{PVM}{RT} \tag{6}$$

Calculation of the pressure drop:

Bernoulli's theory is the relationship between pressure, velocity, and height in a moving fluid, whether it is a liquid or gas. Bernoulli's principle is the concept that an increase in the velocity of a fluid creates a decrease in pressure, and correspondingly as a decrease in the velocity of a fluid causes an increase in pressure. The comprehensive equation of Bernoulli's principle considers the changes in gravitational potential energy and depends on the principle of energy conservation for a fluid flow. The total energy of the fluid before it moves is equal to the energy of the fluid after it is in motion. This correlation is represented by Bernoulli's equation:

$$P_1 + \frac{V_1^2}{2}\rho + h_1\rho g = P_2 + \frac{V_2^2}{2}\rho + h_2\rho g \tag{7}$$

The variables P_1, V_1 and h_1 refer to the pressure, velocity, and height in meter of the fluid at point 1. In the same way, the variables P_2, V_2 and h_2 refer to the pressure, velocity, and the height of the fluid at point 2. The density of the fluid is ρ, and g is the gravitational acceleration constant of 9.81(m/s^2). Pressure drop is the change in pressure between two points of a pipe or tube that occurs as a result of resistance to flow as a fluid flows through the pipe [38]. Factors that will affect the pressure drop in pipes are fluid velocity, wall friction, internal friction such as fluid viscosity, or changes in elevation. The friction loss is affected by the piping network's relatively high rates of roughness, in addition to several pipe fittings, joints, bends, amongst other physical properties. Calculating the pressure drop in a piping system is crucial in selecting the proper pipe diameter and valves for the system. Therefore, it is necessary to determine the overall head loss that occur in the piping system [39]. This is calculated by adding up the major and minor losses:

$$h_L = h_{\text{major}} + h_{\text{minor}} \tag{8}$$

The overall head loss, h_L, for the pipe system consists of the major and minor losses, h_{major} and h_{minor}. Major losses are caused by friction in pipes and ducts, and is given by the Darcy-Weisbach equation:

$$h_{\text{major}} = \frac{V^2}{2g} f \frac{L}{D} \tag{9}$$

Where L and D is the length and internal diameter of the pipe in meter. The friction factor, f, is a dimensionless coefficient that is related to the flow's Reynolds number and relative roughness. The minor losses are caused by components and connections such as valves, bends, tees, or changes in sections, and is given by:

$$h_{\text{minor}} = \frac{V^2}{2g} \sum \zeta \tag{10}$$

For minor losses, $\sum \zeta$ is the sum of all the minor loss coefficients in the pipe's length. The value of ζ varies for the different components and is affected by the component's geometry and the velocity head of the pipe. By combining these two equations, the overall pressure drop is given by:

$$\Delta p_{total} = \frac{V^2}{2}\rho \left(f \frac{L}{D} + \sum \zeta \right) \tag{11}$$

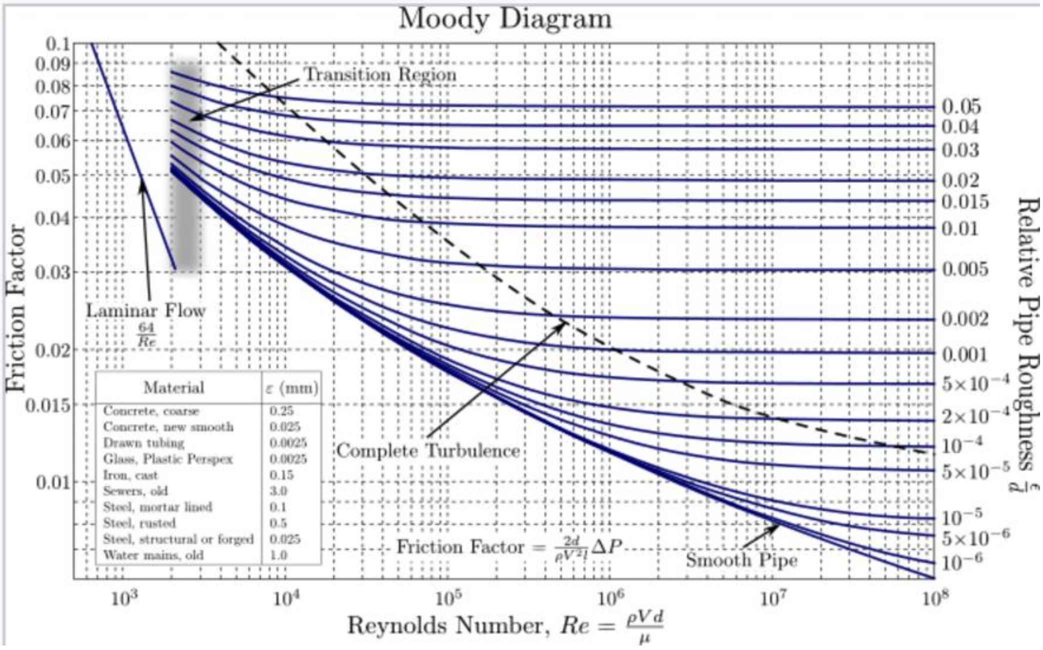
To find the friction factor, f, the following steps are used:

1. Calculate the Reynold's number for the flow
2. Check the relative roughness of the pipe
3. Plot into a Moody diagram

Reynolds number is an important dimensionless number in fluid mechanics. It is defined as the ratio of a fluid's inertial forces to viscous forces and determines the relative importance of these forces in relation to the given flow conditions. The Reynolds number is used to predict if the flow is laminar or turbulent [40]. Laminar flow systems will have low Reynolds numbers, while turbulent flow systems will have high Reynolds numbers. Reynolds number, Re, is determined by the following equation:

$$Re = \frac{\rho VL}{\mu} = \frac{VD}{\nu} \tag{12}$$

Where $\mu\ (Pa * s)$ is the dynamic viscosity and $\nu\ (m^2/s)$ is the kinematic viscosity of the fluid. The Moody diagram shown in Figure 3.2 is a graph between the Reynolds number and the relative roughness of a pipe of circular section through which a fluid flows to determine the coefficient of friction. Relative roughness is the amount of surface roughness that exists inside the pipe. The relative roughness of a pipe is known as the absolute roughness of a pipe divided by the inside diameter of a pipe.



Material	ε (mm)
Concrete, coarse	0.25
Concrete, new smooth	0.025
Drawn tubing	0.0025
Glass, Plastic Perspex	0.0025
Iron, cast	0.15
Sewers, old	3.0
Steel, mortar lined	0.1
Steel, rusted	0.5
Steel, structural or forged	0.025
Water mains, old	1.0

Figure 3.2 – Moody diagram

3.5 Design process

The process of designing a product like the aviation refuelling system is very thorough and demands solid groundwork and accuracy in order to get a proper result. Because this system is initially built as a prototype for testing, it is very important to be thorough and consistent through every step of the design process. This will increase the chances of a successful experience in prototyping and testing. The process includes a lot of jumping between the different design stages as more information is discovered along the way and changes need to be made. Challenges need to be evaluated along the way and the design process includes a lot of problem solving and teamwork to come up with good solutions.

3.5.1 Software

The use of different types of computer software plays a huge role in the design process of mechanical engineering. These are both necessary and helpful tools in the process of establishing piping and instrumentation diagrams (P&ID), 3D-modelling and assembly, and to produce general arrangement drawings (GA). Different types of programmes are used in several steps of the project, depending on what kind of documents are needed. In this project, AutoCAD Mechanical 2020 is the main software used in making the P&ID for the aviation refuelling system. AutoCAD is a computer-aided design and drafting software developed by Autodesk. Another software being used in major parts of this project is Autodesk Inventor Professional 2020. This is a computer-aided design software developed by Autodesk that is used for 3D mechanical design, simulation, visualization, and documentation. The use of these two CAD-software plays a huge role in the process of designing the aviation refuelling system. These are being used throughout the entire project and is the most important tool in the modelling. The logo of these two software are shown in Figure 3.3 and Figure 3.4.

Figure 3.3 –AutoCAD

Figure 3.4. - Inventor

3.6 Experimental method

The following sections will go into detail in how the design process is executed and how the various tools and methods from mechanical engineering is applied in developing a prototype of the aviation refuelling system. This will include illustration, production drawings, 3D-models, and documentation which is gathered and produced throughout the process. The major steps in this process consist of establishing a P&ID, 3D-modelling, production drawings, prototyping, and testing of the prototype.

3.6.1 Piping & instrumentation diagram

Creating a piping and instrumentation diagram (P&ID) of the new aviation refuelling system is an iterative and comprehensive process. In this P&ID it is important to show the different pipelines, where the valves are placed and whether they are normally closed or normally open. All the components in the P&ID are named, numbered (tag), and annotated with all necessary information. The pressure control valve and all of the transmitters and sensors are marked with high level (HL) and low level (LL), or with pressure range and set pressure. The P&ID shows the diameter and port size of all pipelines and components, in addition to flows direction and how the pipes and components are connected. Important information on the main components are described and listed in boxes that includes pressure, capacity, dimensions, temperature, and material. The P&ID for the refuelling system is shown in Figure 3.5. and can be found in Attachment 4. All symbols used in the P&ID are described in Attachment 5.

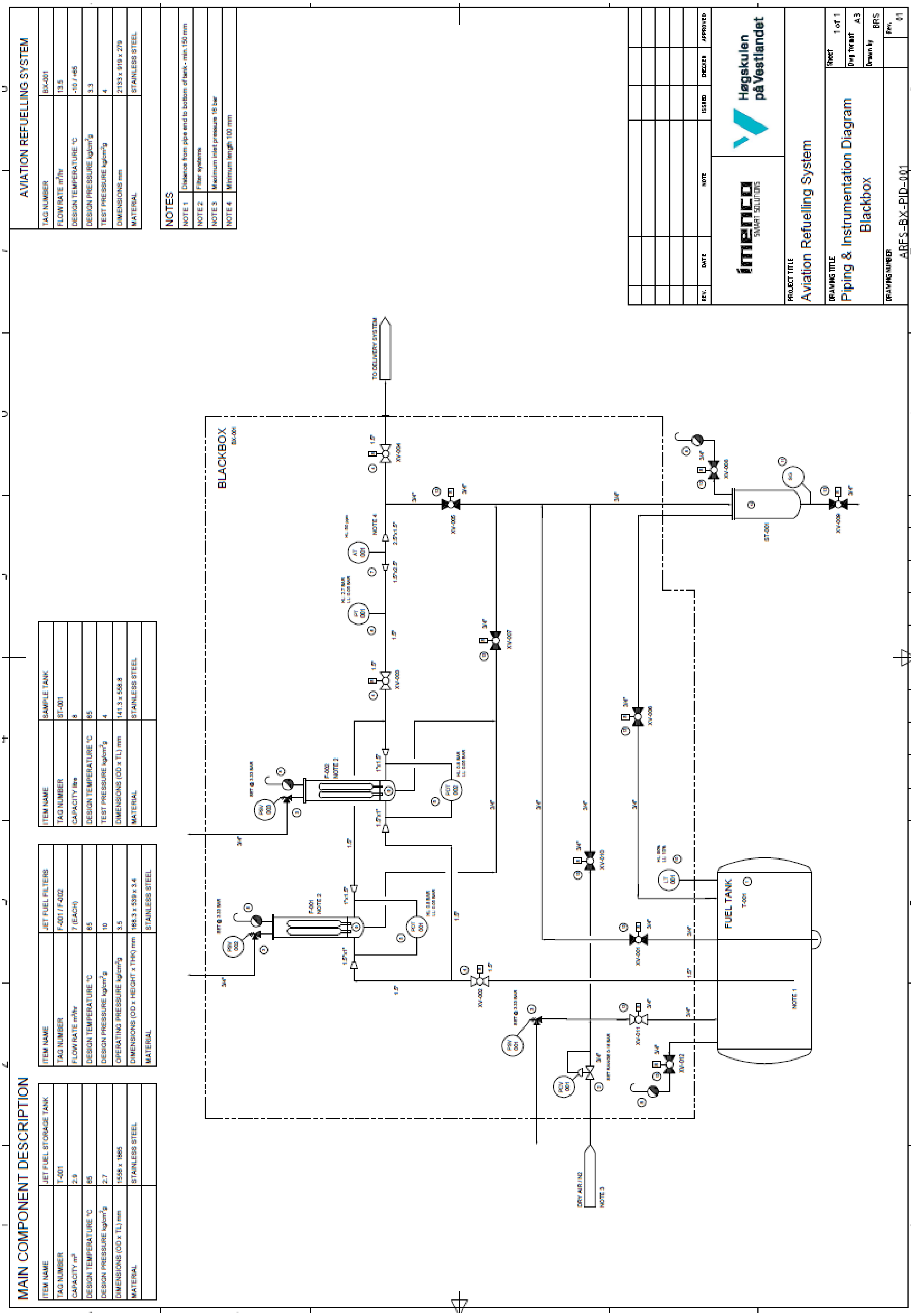


Figure 3.5 – P&ID

3.6.1 Production drawings

Most of the CAD models for components needed in the design process can be accessed online or provided by the manufacturer to use in the assembly of the whole system. The CAD models that are not available can be sketched and modelled in Inventor based on dimensions and other information found in the data or product sheet of the component. If some of the parts needs to be modified or designed by certain requirements differencing from the standard design, it could be necessary to build these parts from scratch. Standard parts such as piping, elbows, reducers, and fittings are available in Inventor's built-in content centre and ready to use in the assembly. Figure 3.6 is a screenshot from Inventor that shows the layout of this content centre.

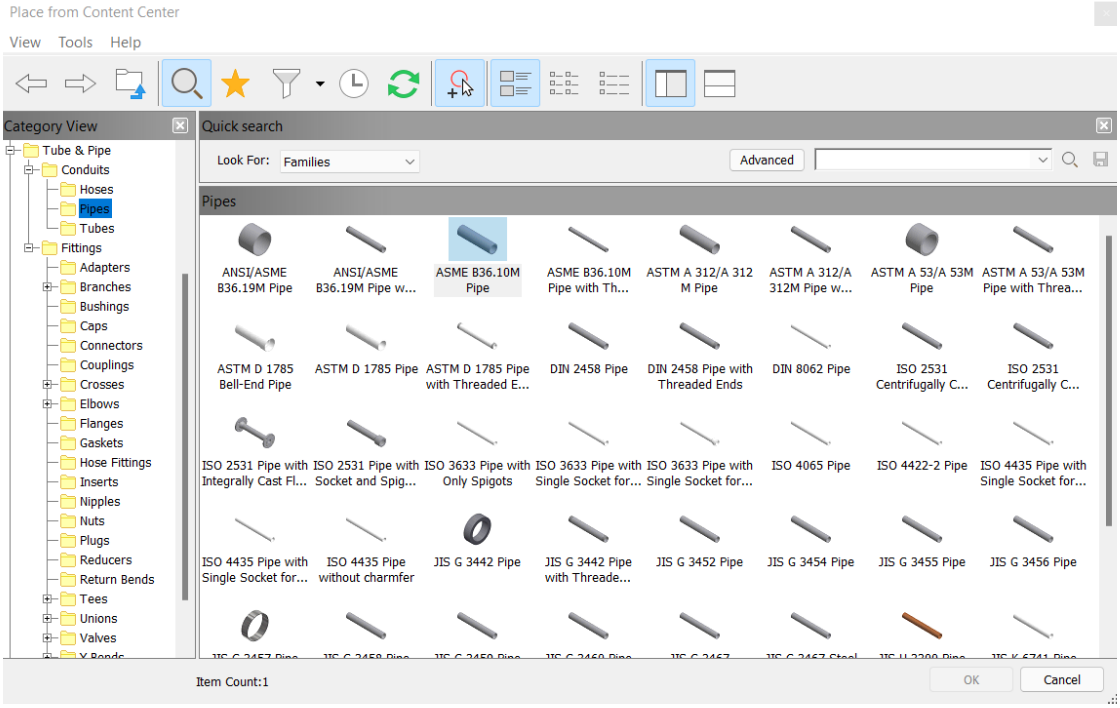


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Figure 3.6 – Content centre in Inventor

The sample tank is one of the components that needs to be modelled to meet the size requirements, in addition to the modified inlets and outlets for piping and drain. The basis for the sample tank design is a similar tank from Imenco that is a bit larger. Most of the parts needed for modelling the sample tank are found in the software's content library, although the rounded tank bottom and the hole cut outs on the top lid must be modified. The sample tank body is made from a standard 5" stainless steel pipe and is fitted with a drain outlet on the bottom. Flanges are placed on the top as a tank lid where holes are cut out to make inlet and outlet ports for pipes and air vent. The sample tank is designed to have a total capacity of 8.5 litre for sampling and testing of the fuel. Figure 3.7 shows a screenshot of the 3D-model built in Inventor of the sample tank that is designed for this system. Production drawings of the sample tank can be found in Attachment 6.

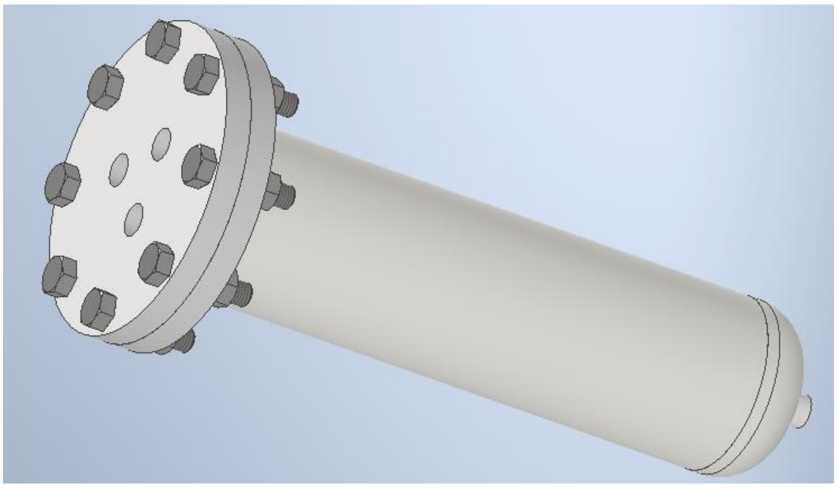


Figure 3.7 – Sample tank

The whole system is to be mounted directly into the manway hole on top of the fuel storage tank. Therefore, all the pipes going into the tank will have to go through the tank lid. This is supposed to be the base for the whole system, and everything is built around the tank lid. In order to reduce the size of the whole design, the filter vessels are also being mounted and hung from the tank lid and into the tank through the manhole. The tank lid cut-out is therefore being machined to fit the manway and clamps for sealing, holes to place both filter vessels, in addition to holes for inlet and outlet of all the pipes going into the tank. Production drawings of the tank lid cut-out are found in Attachment 7. Figure 3.8 shows the 3D-model of the tank lid cut-out.

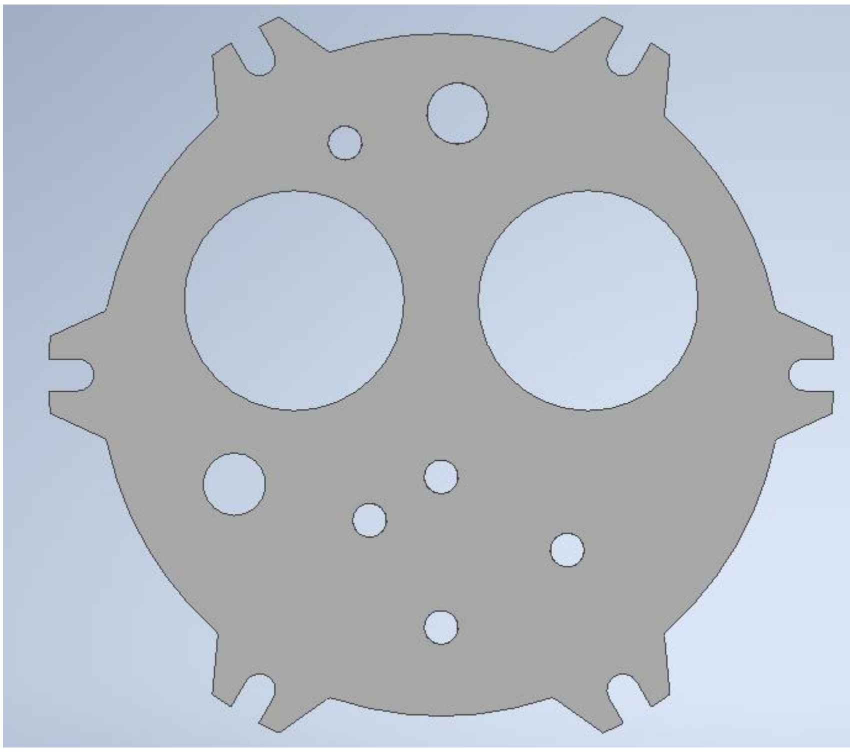


Figure 3.8 – Tank lid cut out

When all the necessary parts, pipes, and fittings are modelled and ready, the system is put together and assembled with Inventor. The assembly process can be challenging because all parts must be placed and fitted in the correct position for the system to function properly. There is not only a lot of rules to take into consideration on how and where the different components are placed, but also for the system to come together as one piece it is important that the piping is properly dimensioned. The overall assembly design is mainly based on the layout from the P&ID. Therefore, it is essential to establish a detailed P&ID before starting on the modelling to understand the function of each part. Figure 3.9 and Figure 3.10 are screenshots of the finished model from different angles. The production drawings of the whole system are found in Attachment 8.

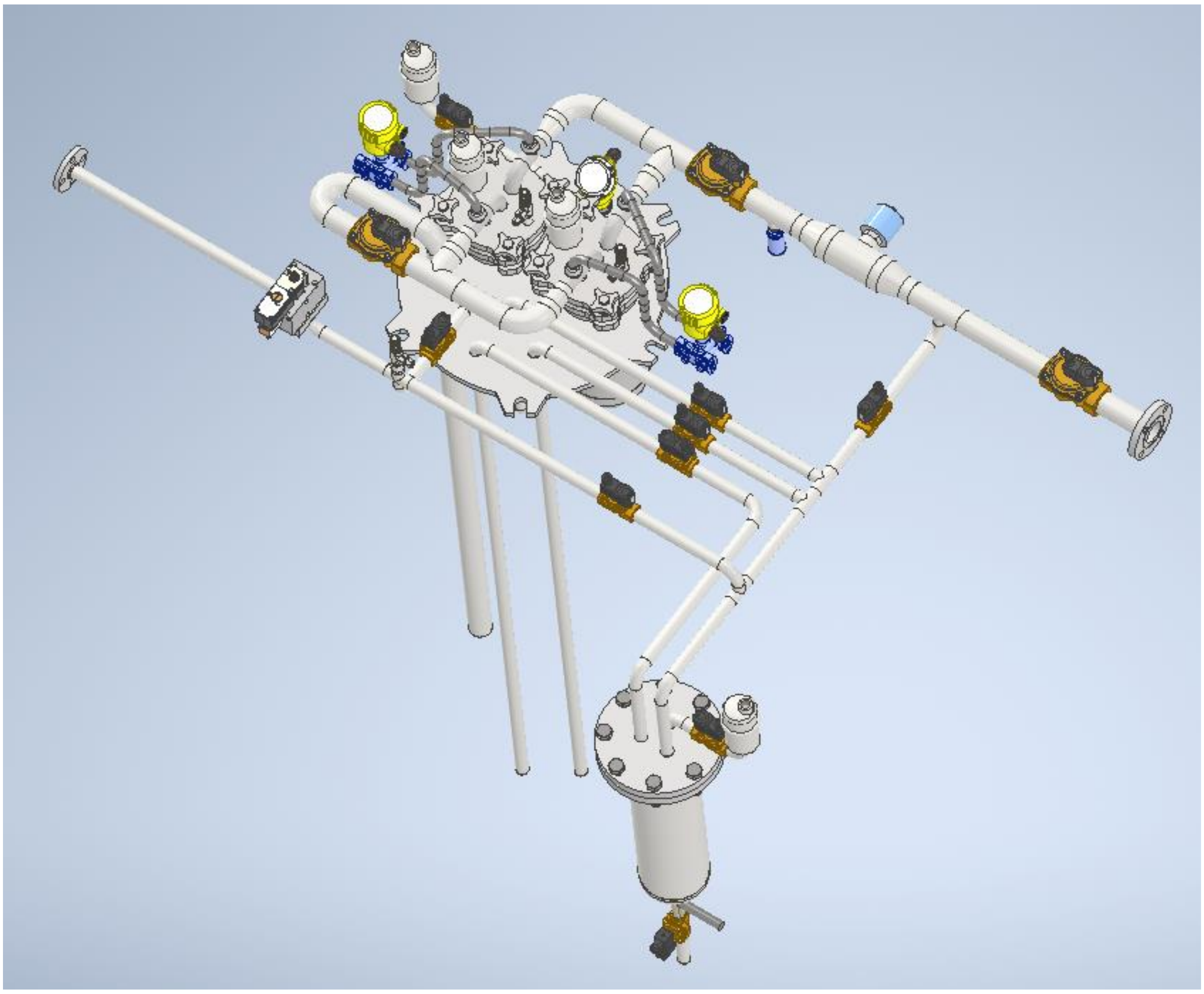


Figure 3.9 – 3D-model of whole system

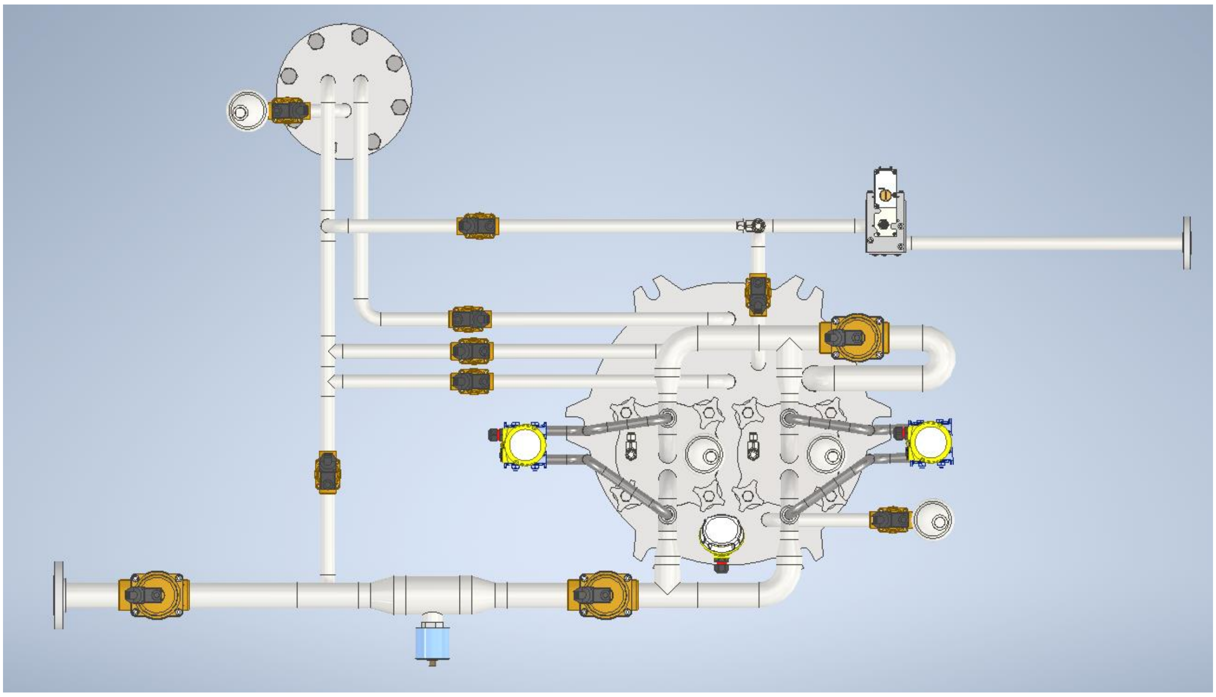
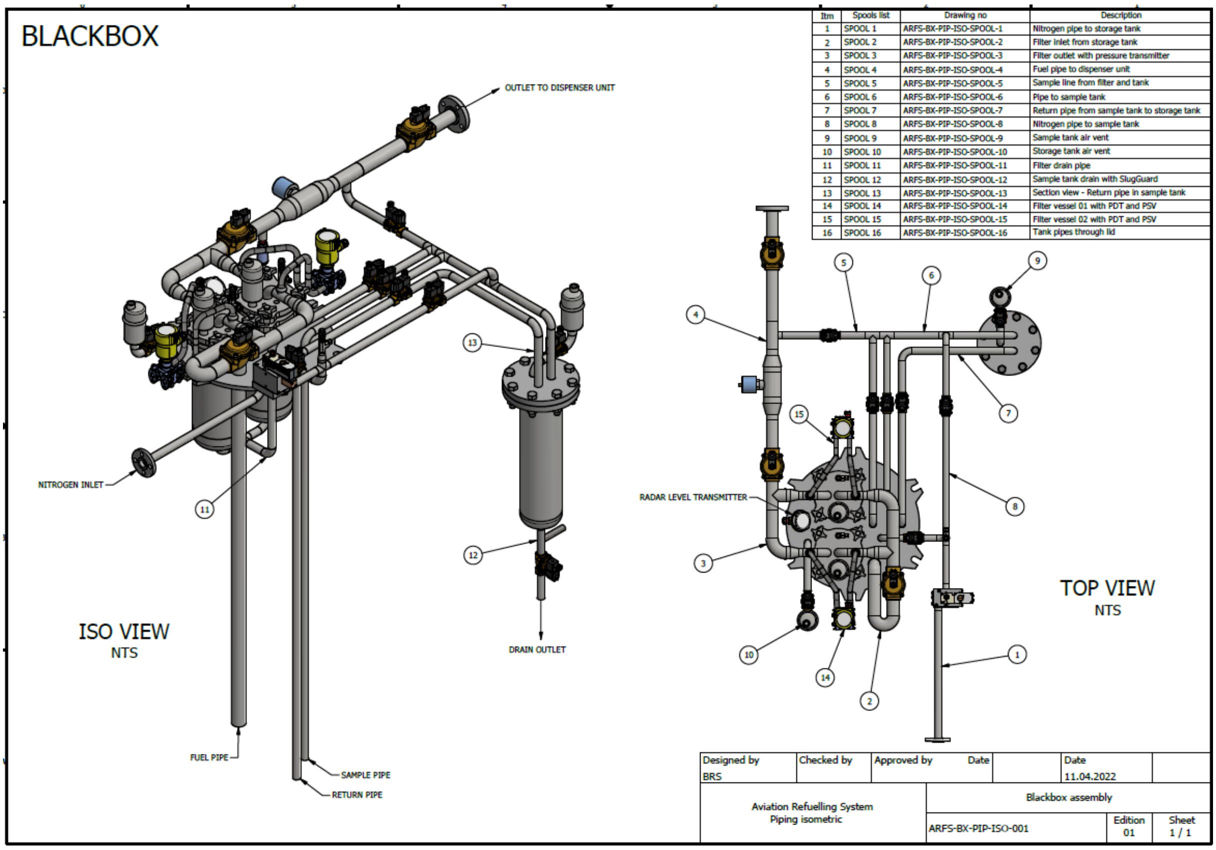


Figure 3.10 – 3D-model from above

For the mechanics to be able to build an actual prototype of the modelled system, it is necessary to establish proper GA drawings with all the documentation needed for production. These production drawings must include all dimensions for every section of the assembly, so that the mechanics have all the information they need in the building process. In addition, they will need separate drawings of any parts that are modelled or modified. Because this is a large system with many parts and components, the production drawings are split into smaller segments (spools) of separate drawings. This gives a better overview of each segment and makes it easier to get all the correct dimensions and annotations. The spools are numbered and named on the GA drawing to match the attached spool drawings, as shown in the piping isometric in Figure 3.11. The complete list of GA drawings with corresponding spools are found in Attachment 9. On every spool drawing there is a bill of materials (BOM) that includes the name, model, type, and material of every part or component. The BOM is being used to order all the parts needed for building the prototype.



Itm	Spools list	Drawing no	Description
1	SPOOL 1	ARFS-BX-PIP-ISO-SPOOL-1	Nitrogen pipe to storage tank
2	SPOOL 2	ARFS-BX-PIP-ISO-SPOOL-2	Filter inlet from storage tank
3	SPOOL 3	ARFS-BX-PIP-ISO-SPOOL-3	Filter outlet with pressure transmitter
4	SPOOL 4	ARFS-BX-PIP-ISO-SPOOL-4	Fuel pipe to dispenser unit
5	SPOOL 5	ARFS-BX-PIP-ISO-SPOOL-5	Sample line from filter and tank
6	SPOOL 6	ARFS-BX-PIP-ISO-SPOOL-6	Pipe to sample tank
7	SPOOL 7	ARFS-BX-PIP-ISO-SPOOL-7	Return pipe from sample tank to storage tank
8	SPOOL 8	ARFS-BX-PIP-ISO-SPOOL-8	Nitrogen pipe to sample tank
9	SPOOL 9	ARFS-BX-PIP-ISO-SPOOL-9	Sample tank air vent
10	SPOOL 10	ARFS-BX-PIP-ISO-SPOOL-10	Storage tank air vent
11	SPOOL 11	ARFS-BX-PIP-ISO-SPOOL-11	Filter drain pipe
12	SPOOL 12	ARFS-BX-PIP-ISO-SPOOL-12	Sample tank drain with SlugGuard
13	SPOOL 13	ARFS-BX-PIP-ISO-SPOOL-13	Section view - Return pipe in sample tank
14	SPOOL 14	ARFS-BX-PIP-ISO-SPOOL-14	Filter vessel 01 with PDT and PSV
15	SPOOL 15	ARFS-BX-PIP-ISO-SPOOL-15	Filter vessel 02 with PDT and PSV
16	SPOOL 16	ARFS-BX-PIP-ISO-SPOOL-16	Tank pipes through lid

Designed by BRS	Checked by	Approved by	Date		Date 11.04.2022	
Aviation Refuelling System Piping isometric		Blackbox assembly				
		ARFS-BX-PIP-ISO-001			Edition 01	Sheet 1 / 1

Figure 3.11 – Piping isometric

3.6.2 Prototyping

The process of manufacturing an operational prototype of the aviation refuelling system is based on the documentation of P&ID, BOM and production drawings provided by the engineers. The mechanics are using this information to build the system while the automation team are programming the control system based on the functional description provided. Before initializing the assembly process, it is important to make sure that all the components and parts for the model are obtained and available to the mechanics. Some of the parts are available from Imenco's workshop, while other parts are ordered from different manufacturers. The first version of the prototype is only supposed to be a simple model of the system to perform tests on functionality and does not have to meet the exact requirements of appearance and design. During the assembly of this prototype, the mechanics are making some changes and adjustments to the assembly due to practical reasons such as economic resources and limited time.

Changes that are done is mostly related to piping, tubing, connections, and fittings. All of the ¾" piping will be replaced by 20 mm tubing because flexible tubing is more practical in terms of time and cost saving than welding pipes. The sample tank shown in Figure 3.12, originally designed from a 5" diameter pipe, is being increased to a 6" diameter pipe as this is much easier to obtain. Due to the increase of the sample tank diameter, the cut-out holes for inlets and outlets on the lid is placed further apart as shown in Figure 3.13.

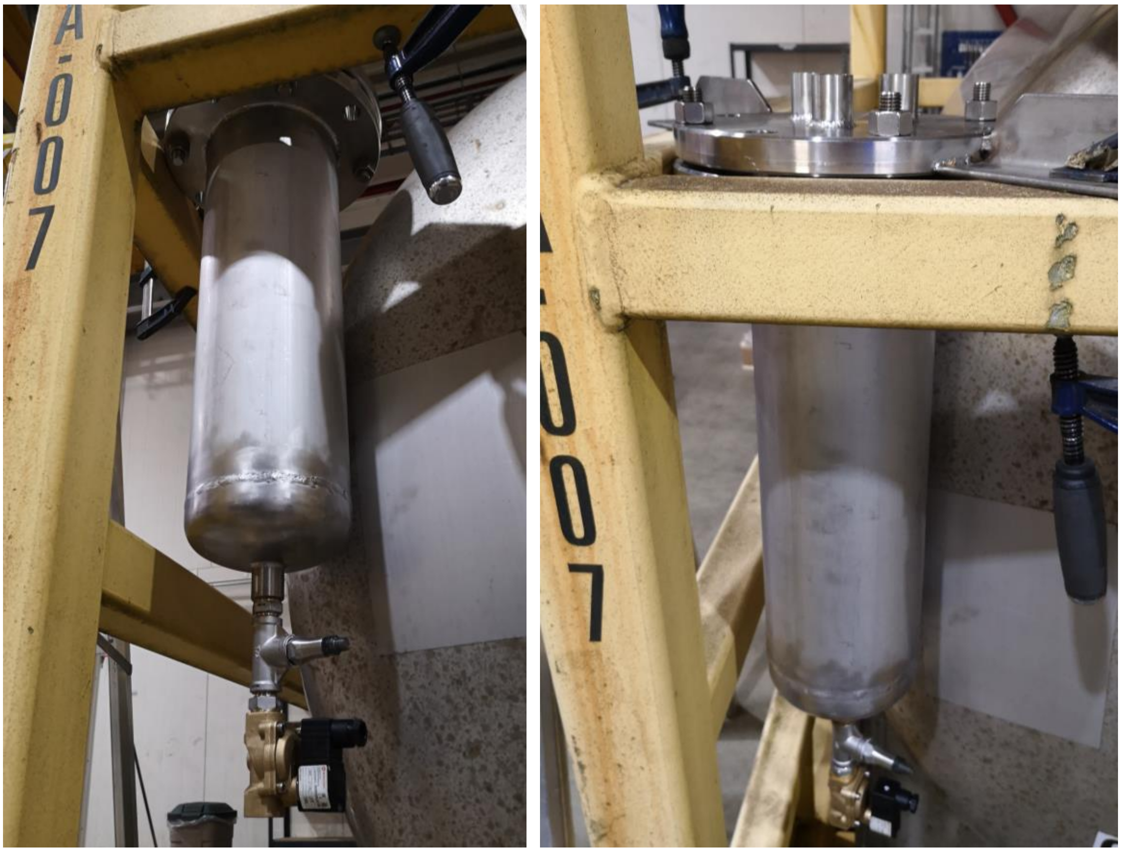


Figure 3.12 – 6’’ Sample tank

Figure 3.13 – Sample tank lid

The compressed air supply pipeline is also being replaced by 25 mm tubing. In order to perform necessary maintenance on the system and replacing the filter vessels when needed, the inlet and outlet of the filter vessels will be fitted with flanges instead of welding as shown in Figure 3.14. In addition, the solenoid valve on the filter vessel inlet is fitted with unions. Originally, the requirements for mounting the AFGUARD water sensor is a 2 ½'' pipe with a minimum length of 100 mm, this is reduced to a 2'' pipe because of difficulties with procurement of the initial required pipe diameter.

Figure 3.14 – Tank lid with filters in building process

3.6.3 System operations

The following sections will describe the different modes or operations of the refuelling system. This is illustrated by pictures from the human-machine interface (HMI) provided by the automation department at Imenco. The refuelling system will have four different modes that consist of a refuelling mode, auto sampling mode, start sampling mode, and maintenance mode. The green lines demonstrate the direction of the fuel flow for each mode. Green valves indicates that the valves are open, while red valves means that they are closed. The complete functional description for these modes is included in Attachment 10.

Refuelling mode

The main function of this mode is to deliver jet fuel from the storage tank to the dispenser unit. The refuelling mode is initiated from a local HMI. The green lines shown in Figure 3.15 indicates the flow path for this mode. When the refuelling mode command is given, the pressure control valve (PCV-001) will fully open in order for the nitrogen to enter the storage tank with a pressure of 2.67 bar. The pressure from the nitrogen will push jet fuel from the storage tank and into the system with a flow rate of 225 lpm. Only the fuel pipe valves will be open in this mode, while all other valves going in or out from the sample tank will stay closed. The fuel will flow through both filters and into the dispenser unit after passing the pressure transmitter (PT-001) and the water sensor (AT-001). When the refuelling is finished, the process will stop on command from HMI.

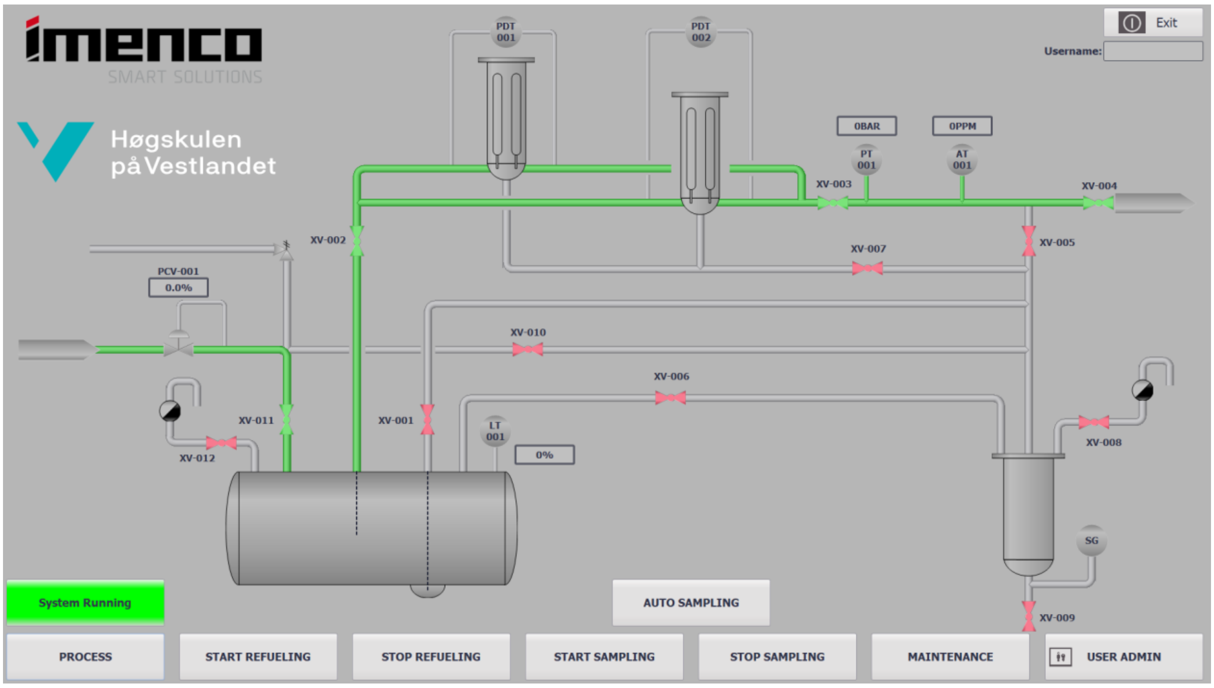


Figure 3.15 – Refuelling mode HMI

Fuel sample mode

Sampling and testing is important to detect any contamination or water particulates in the jet fuel from any point of the system. There should not be any water in the fuel that is delivered from the storage tank. This mode is also used for daily test runs of the system so that the process does not sit for too long when not in use. When the system is not in use for some time, there is a risk of debris build-up and microbial growth in the pipes that may cause corrosion or potentially fuel contamination. Sampling is done from the storage tank sump, filter sump, and fuel pipe, before it is recycled back into the storage tank. During any sample mode the differential pressure transmitters (PDT) are ignored and will not alert of any pressure drop across the filters. The sample mode consists of six automatic sequences for sampling, testing, and recycling. These are divided into sections that are automatically run through when the mode is initiated by either a local HMI or remote HMI via network connection. The first section indicates the ongoing automatic sampling, while the remaining sequences are described and illustrated in the following sections of this chapter.

Fuel sampling mode can be initiated in two different ways, either “auto sampling” or “start sampling”. When the automatic sample mode is initiated, the sampling will start automatically at midnight and runs through all sequences without the requirement of any supervision. If the sample mode is initiated with the “start sampling” function, the sampling will start immediately and runs through all sequences at the time of initiation. This mode can be stopped manually at any point with the “stop sampling” function. Additionally, there is a maintenance mode that allows the operator to manually control any valves or modes separately. This mode is password protected to prevent any errors that may cause damage to the system or safety issues.

These modes do not require the same pressure and flow rate as the refuelling mode. Therefore, the pressure control valve (PCV-001) only needs to be partially open when moving the fuel. Nitrogen is let into the storage tank in all sections where fuel needs to be moved. The sample tank air eliminator valve (XV-008) is open during this mode in order to create pressure in the system by venting the sample tank. Without venting the sample tank, the fuel will not move through the system. When the storage tank is empty and needs to be refilled with fuel, the manway lid is opened, and the system is pulled out to make room for the fuel hose. Any nitrogen left in the storage tank is let out into atmosphere.

Section #2: Sampling from storage tank

This mode is the second step in the automatic sample mode. It is used for sampling and testing of jet fuel directly from the storage tank sump without passing through the filters. The green lines shown in Figure 3.16 indicates the flow path for this mode. Jet fuel is transferred through tubing from the storage tank sump and into the sample tank where it is tested.

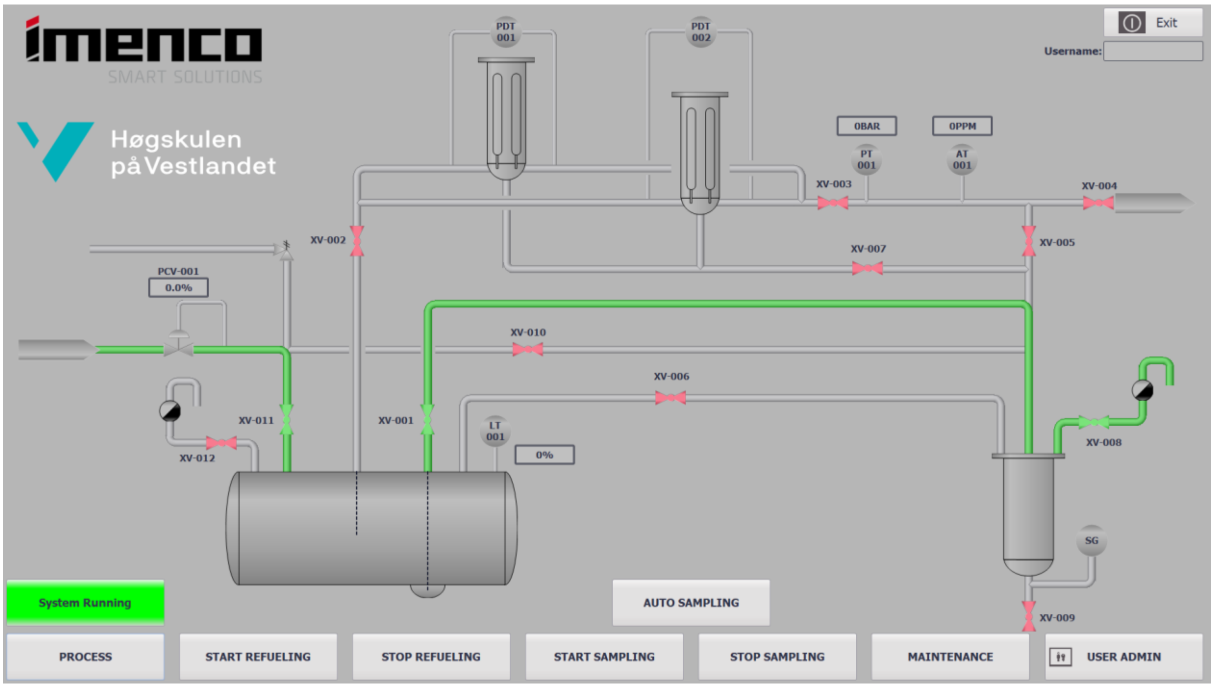


Figure 3.16 – Sampling mode HMI

Section #3: Sampling from filter vessels

This is the third step in the automatic sample mode and is used for sampling and testing of fuel from the filter sump of both filter vessels. The green lines shown in Figure 3.17 indicates the flow path for this mode. Jet fuel is transferred into both filters through the fuel pipe from the storage tank. To prevent the fuel from flowing further through the fuel pipe, the valve on the filter outlet side is closed. This means that the fuel will not pass the water sensor (AT-001). Instead, fuel is drained through tubing directly from the filter sump into the sample tank where it is tested.

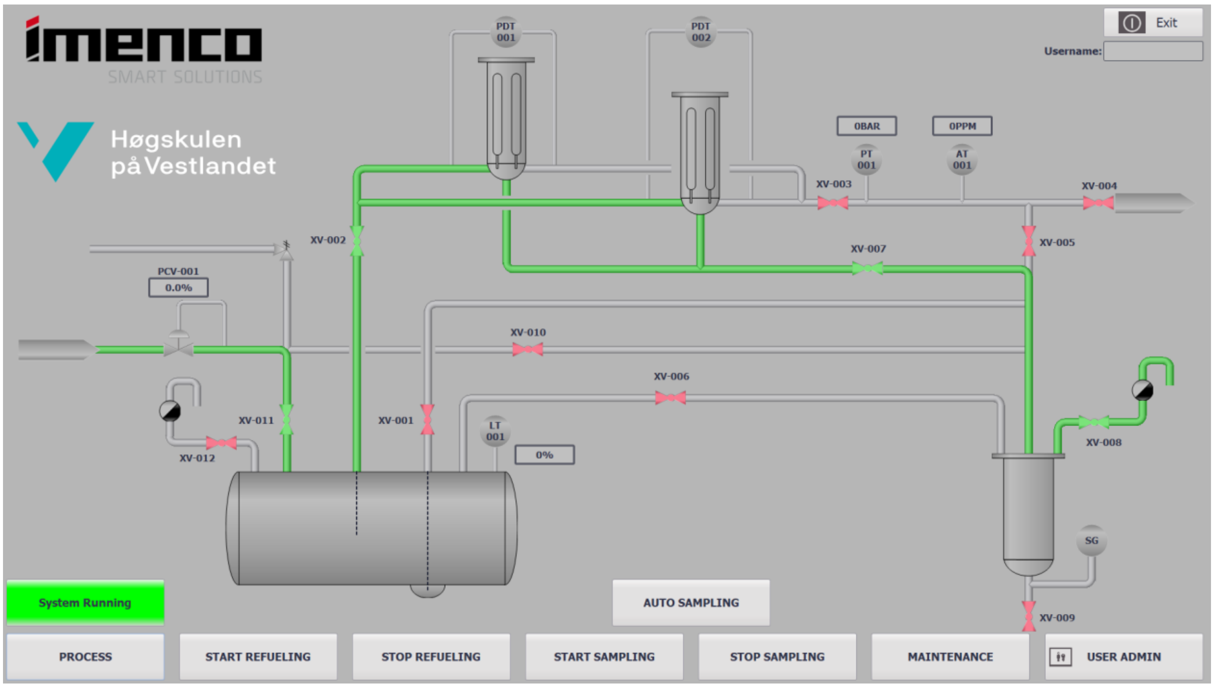


Figure 3.17 – Sampling mode filter sump, HMI

Section #4: Sampling from fuel line

This is the fourth step in the automatic sample mode and is used for checking the fuel from the fuel pipe. The green lines shown in Figure 3.18 indicates the flow path for this mode. Jet fuel will pass through all components as it normally would in the ordinary refuelling mode, including both filters and the water sensor (AT-001). The average value of the water sensor (AT-001) will be checked, displayed, and stored. Instead of the jet fuel being delivered to the dispenser unit, it is transferred through the tubing going into the sample tank where it is tested.

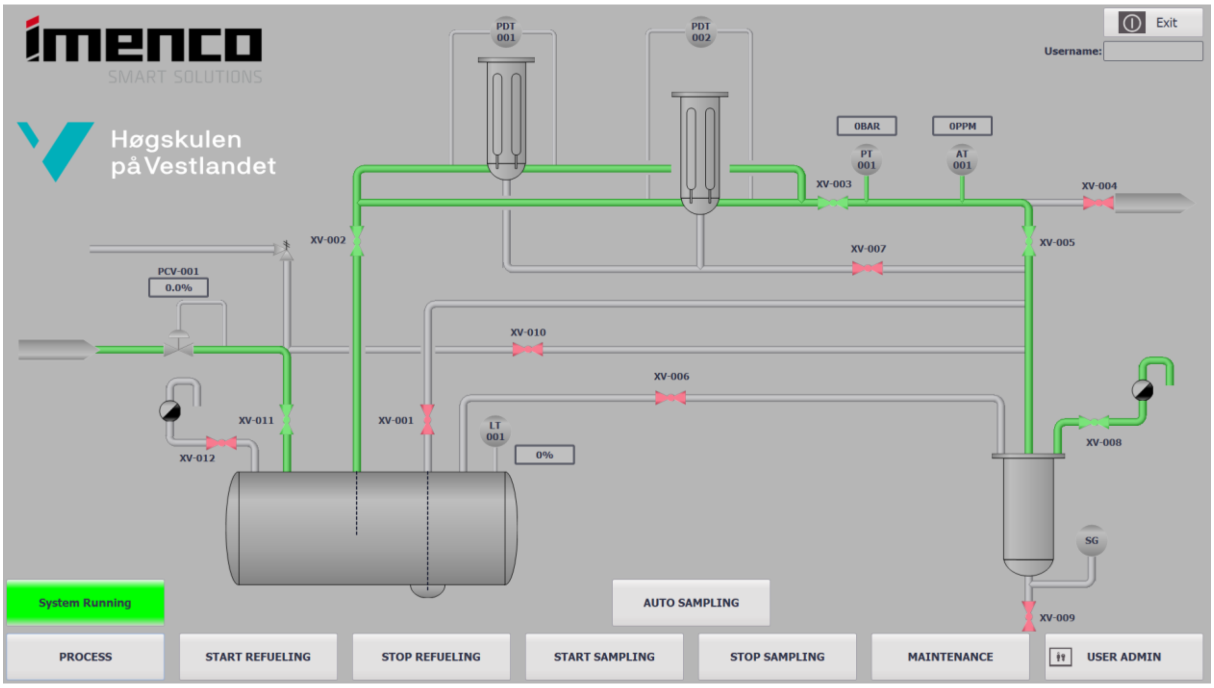


Figure 3.18 – Sampling mode fuel pipe, HMI

Section #5: Settling time and fuel quality check

When the sampling and testing is complete, all valves will be shut off while the fuel settles in the sample tank. Fuel from all the sample sequences is now mixed in the sample tank. This section will allow the sampled fuel to settle for a set time in order to perform proper fuel quality check. Normally the settle time will be set to 3 hours per meter of fuel, in order to allow any water in the fuel to sink down to the bottom of the sample tank. If the water sensor (SG) installed at the drain point alerts of any water in the fuel, the drain valve (XV-009) will open in order to empty the sample tank. The contaminated fuel will have to be drained from the sample tank to prevent any water particulates from recycling back into the storage tank. If the water sensor does not alert of any contamination at the sample tank drain point, the automatic sampling mode will safely be able to proceed to the final recycle sequence of this mode, where the jet fuel is returned to the storage tank.

Section #6: Recycle from sample tank to storage tank

The final step in the automatic sampling mode is the recycle sequence. The green lines in Figure 3.19 indicates the flow path for this mode. The function of this step is to recycle the fuel from the sample tank back into the storage tank after all sampling and testing is done. In order to do this, the pressure control valve (PCV-001) is open to move nitrogen through tubing directly to the sample tank. The air eliminator mounted on the storage tank needs to be open in order to create pressure in the system for the fuel to move. All of the fuel left in the sample tank is returned back into the storage tank and the sample mode is completed.

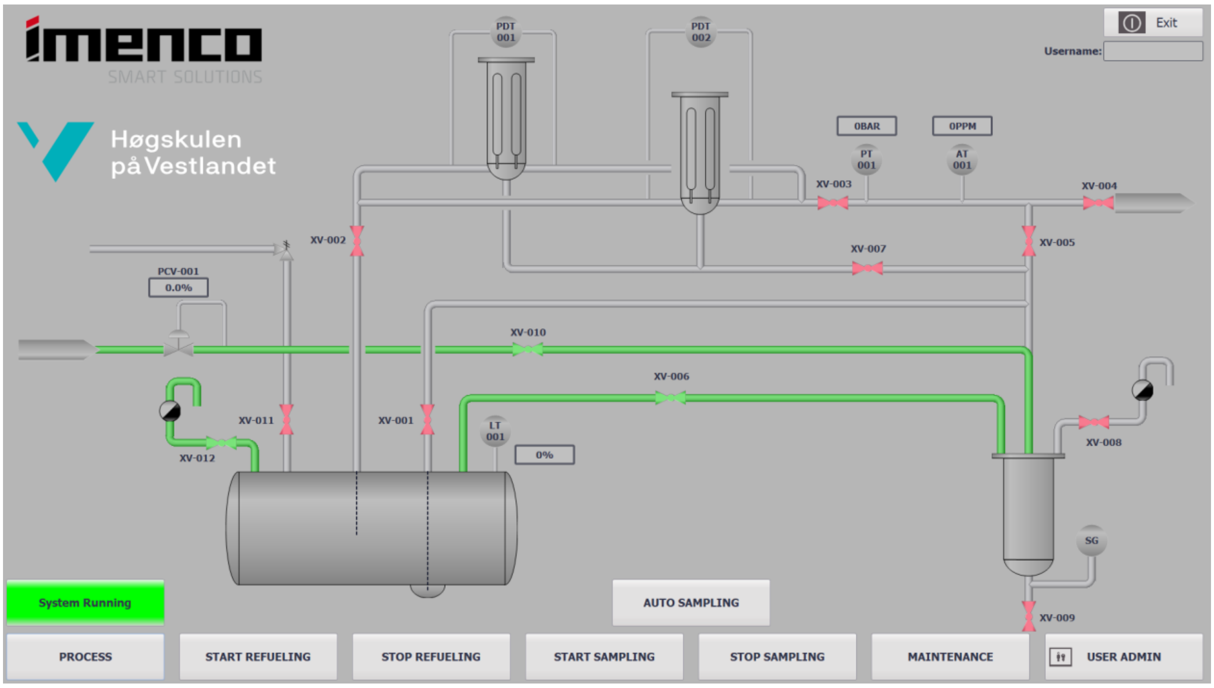


Figure 3.19 – Recycle mode, HMI

3.7 Testing

The prototype is tested with jet fuel in Imenco’s mechanical workshop. Because this is an early-stage prototype, all testing is done with compressed air instead of nitrogen. The compressed air is supplied directly from pipes in the workshop with a pressure of 7.5 bar, while the PCV is set to deliver 3 bar into the system. The storage tank is equipped with a built-in PSV that is set to blow out at 2.2 bar. This will prevent the process from reaching the tank’s maximum pressure of 2.67 bar in order to protect the tank from any damage. Figure 3.20 shows the prototype rigged for testing with cables for automation connected to a programmable logic controller (PLC). This is controlled manually from a computer through an ethernet cable. The HMI shows real-time values of the measured parameters in the system while running, and alerts if any error occurs. For the sample mode sequence, each section of sampling is set to 5 seconds and the process is done in a total of 15 seconds. The settle time in the sample tank is set to 30 seconds instead of the required 3 hours per meter of fuel.

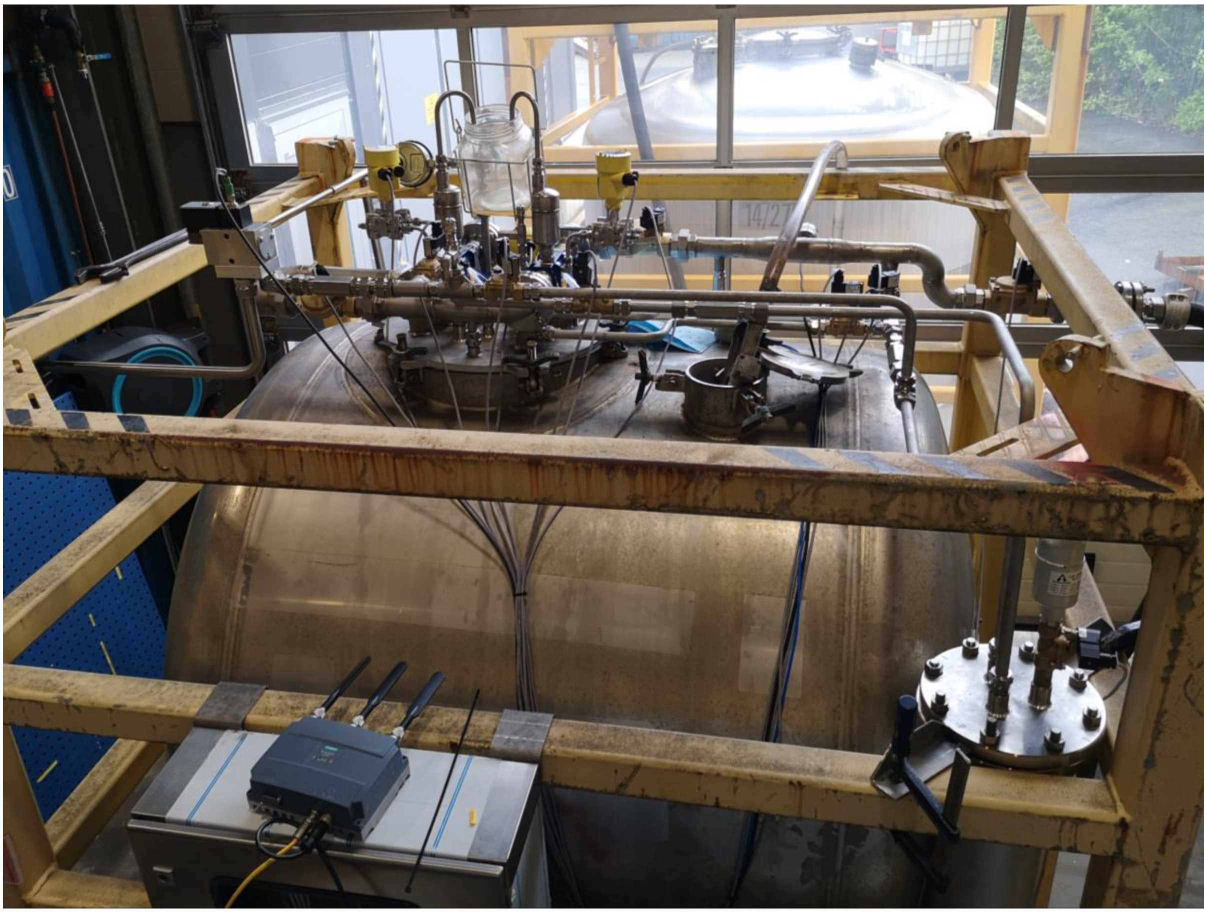


Figure 3.20 – Prototype rigged for testing

When the refuelling mode is running, the system transfers fuel into another storage tank placed outside the workshop. The fuel hose is equipped with a master flow meter, shown in Figure 3.21, to monitor the fuel flow during this process. This flow meter has to be sent in for calibration frequently in order to maintain its high accuracy of flow measurement.

Figure 3.21 – Master flow meter

A manometer is mounted on top of the system to monitor the process pressure during the test runs, see Figure 3.22 The sample tank is equipped with a ball valve on the drain outlet during test runs of the sample mode to allow the fuel to be emptied into a bucket.

Figure 3.22 – Manometer on prototype for testing

Three check valves are also installed in the system for the test runs. These are placed on the tubing going into the sample tank, on the tubing going back to the storage tank from the sample tank, and one on the gas supply pipe going into the storage tank. Figure 3.23 shows the placement of these valves in the system. The reason why check valves are installed is because the solenoid valves only close in one direction and the check valves will prevent compressed air from flowing in the wrong direction and leaking through the closed valves. The changes made during prototyping and testing are included in the updated P&ID found in Attachment 11. The blue circles seen in the figure marks the placement of the check valves that are installed in the prototype.

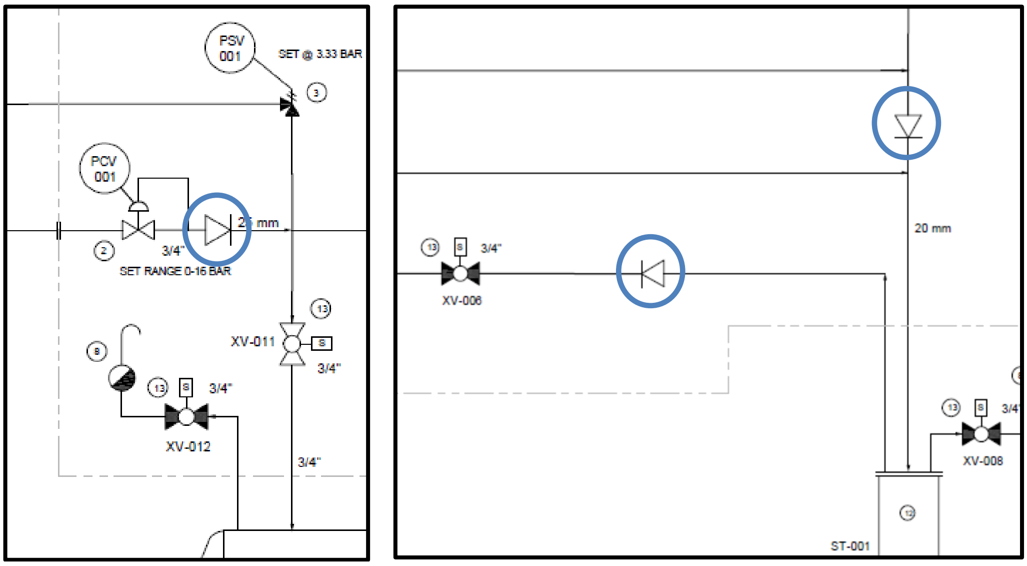


Figure 3.23 - Cropped screenshots of P&ID showing check valve placement

3.8 Source of error

In mechanical design and prototyping of a concept-based product, there will naturally be risks of many different sources of error during the design phase, prototyping phase, and test phase. When building a prototype there are several obstacles that may occur throughout the process. These could be human errors in assembling and operating the system, or mechanical errors that may cause malfunction of the system. Another typical source of error may be delays in procurement due to extended delivery time on components and parts needed for prototyping, or troubles with obtaining certain components in general, depending on availability and costs. These delays may affect the progress of the project itself, in addition to having an impact on the outcome of the final prototype.

During the workshop test runs of the prototype, problems like leakage within the system or to the environment could be a source of error. Leakage may occur in faulty welding or damaged components. This will potentially affect the outcome of the prototype test runs in terms of pressure and flow. The system design, piping, and components are based on calculations of jet fuel and nitrogen as flow medium. Since the prototype testing will be done with compressed air instead, it is natural to expect some deviation in the test results due to changes in pressure, flow, and friction. Test results may also be affected by the accuracy of any instruments used for measuring during the testing.

4. Results

This chapter will present the final design result of the aviation refuelling prototype, along with a description of the main components used in the system and their function. This will be followed by results from the process calculations and prototype testing.

4.1 Design result

The final design result may differ from the earlier production drawings and 3D-model due to changes and adjustments made by the mechanics when building the prototype. Figure 4.1 shows the final design of the prototype mounted directly on the manway of the storage tank. Some alterations are made to the piping and tubing in terms of bending and shaping for the system to fit onto the tank and frame.

Figure 4.1 – Final prototype design

4.2 Components

The choice of components and their placement on the prototype is based on the function of each section in the system. For the process to run smoothly it is essential that these components are placed in the right position and operate properly with the rest of the equipment. All components are evaluated and chosen based on calculations including pressure, flow, and velocity. Their material and technology should be suitable for both jet fuel properties and offshore conditions. It is important that the components can withstand the operating pressure of the system to avoid any failure or damage during testing of the prototype. In order for the design to be as compact as possible, it is necessary to reduce the number of components in the system to fit the wanted dimensions. The following sections will describe a selection of main components used in the system, along with their placement and function the process.

4.2.1 Filter vessel

The filter vessels used in the prototype of the aviation refuelling system is a VFH-1-355 Type S jet fuel filter delivered by Faudi (Attachment 12) This is a two-stage water filter separator that meets the requirements of EI 1581 6th Edition for use with Jet A-1 fuel. The vertical filter housing (VFH), shown in Figure 4.2 consists of a coalescer element and a separator element to remove free water and other contaminants from the fuel. Because of the filter's capacity of just 160 litre per minute, two filters are installed in parallel to ensure that the system is able to maintain a flow rate of 225 litre per minute while running. In order to achieve such high flow rates with only one filter instead of two, the filter would be too big for the prototype and would not fit the wanted dimensions of the system.

Both filter vessels are mounted with a pressure safety valve (PSV) and air eliminator on top. The PSV is the DK-LOK V66 Series relief valve (Attachment 13). The air eliminator is an Armstrong Model 11AV free floating lever air/gas vent (Attachment 14). The standard design is made from stainless steel with 1" flanged inlet and outlet ports on the top and a drain port at the bottom. Differential pressure transmitters (PDT) are mounted on top of each filter with tubing to monitor any pressure drop across the filters. A pressure drop of 0.7 bar or higher will indicate that the filter is dirty or fouled and needs to be replaced.

Figure 4.2 – Filter water separator

4.2.2 Sample tank

The sample tank for the refuelling system consists of a 6" pipe with a slip-on flange and blind flange mounted on top as the lid. These are held together by hex bolts and nuts. Three holes are machined on top of the blind flange as inlet and outlet ports for the tubing. Additionally, the tank bottom has a drain port that is fitted with a solenoid valve and an electronic sensor for detecting any water in the fuel. The tank is mainly used for sampling and testing of the fuel quality from the fuel tank and filter sumps, as well as regular intervals of test runs in the system. Sampling and testing of the fuel is fully automated and remotely operated so that the process can be controlled via PLC. The test results are generated and sent back to the computer, so there is no need for any manual sampling of the fuel. In order to empty the sample tank, the fuel will be recycled back to the storage tank. An Armstrong 11AV air eliminator is mounted on the tank lid to vent out any nitrogen in the tank after recycling the fuel. The sample tank built for the prototype is pictured in Figure 4.3 and is able to hold around 12-13 litres of fuel.

Figure 4.3 – Sample tank on prototype

This new solution for sampling does not meet today's requirements of the CAP 437 standards for manual sampling and testing. Therefore, the fuel should be tested as follows on exemption from the regulations in the beginning. Should this automated solution prove to function well, it should be suggested that the CAP 437 standards can be changed in the long term. This could eventually remove the requirement of having trained offshore personnel present for manual sampling and testing of the fuel quality. However, this would be a solution far from the prototype stage of developing this type of refuelling system.

4.2.3 Solenoid valves

The valve used in the system is the ST-IA-series solenoid valve delivered by Norgren (Attachment 15). Figure 4.4 shows the normally closed, indirect operated 2/2-way solenoid valve. The valve has one inlet port and one outlet port, with two positions of either closed or open position. When the normally closed solenoid is energized, the piston will lift to let the fluid pass through. Indirect operated solenoid valves can control a high flow rate and can only be used in one flow direction. Ideally the valve body should be made from stainless steel material suitable for offshore conditions, but for the purpose of testing the system in a workshop the cheaper choice would be brass.

Figure 4.4. – Norgren solenoid valve

The majority of solenoids used in the system have 3/4" ports, except for the fuelling pipe from the storage tank to dispenser unit where 1 1/2" ports are being used. The main purpose of solenoid valves in the refuelling system is to shut off the flow in certain sections to direct the fuel flow depending on which mode is running. Some of the solenoid valves are also being used for air vent and drain purposes. Figure 4.5 shows one of the 1 1/2" solenoid valves mounted with unions.

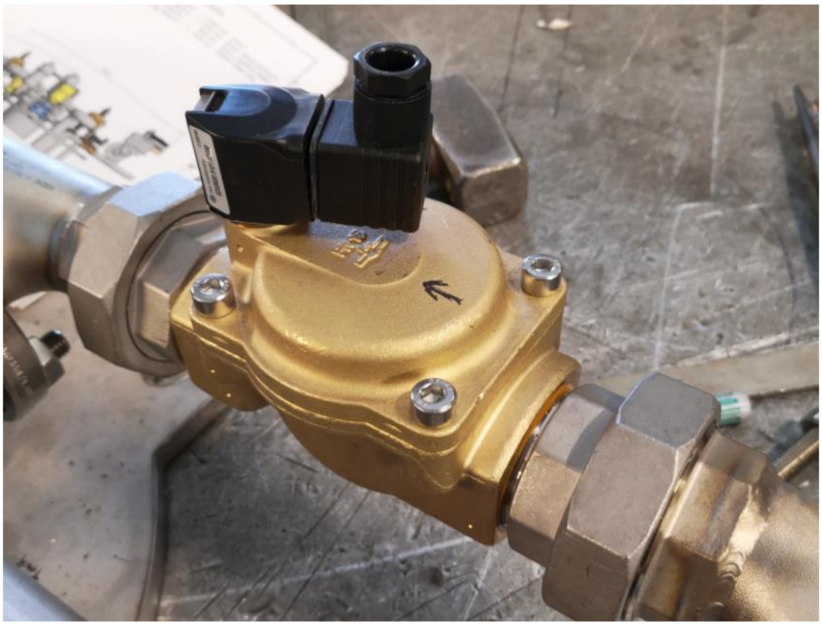


Figure 4.5 – Solenoid valve mounted on prototype

4.2.4 Pressure control valve

The pressure control valve (PCV) used in the system is the VP23 series delivered by Norgren (Attachment 16). The PCV shown in Figure 4.6 is a 3-way closed loop proportional pressure control valve. The PCV is used to control the air pressure from the air supply to the fuel storage tank. The valve is normally closed and has three ports, port 1 for inlet pressure, port 2 for outlet pressure, and port 3 for venting. This model has a pressure range of 0-16 bar. The current loop is a 4-20mA control signal, and the power supply is 24 Volt DC. The valve housing is made from aluminium material.

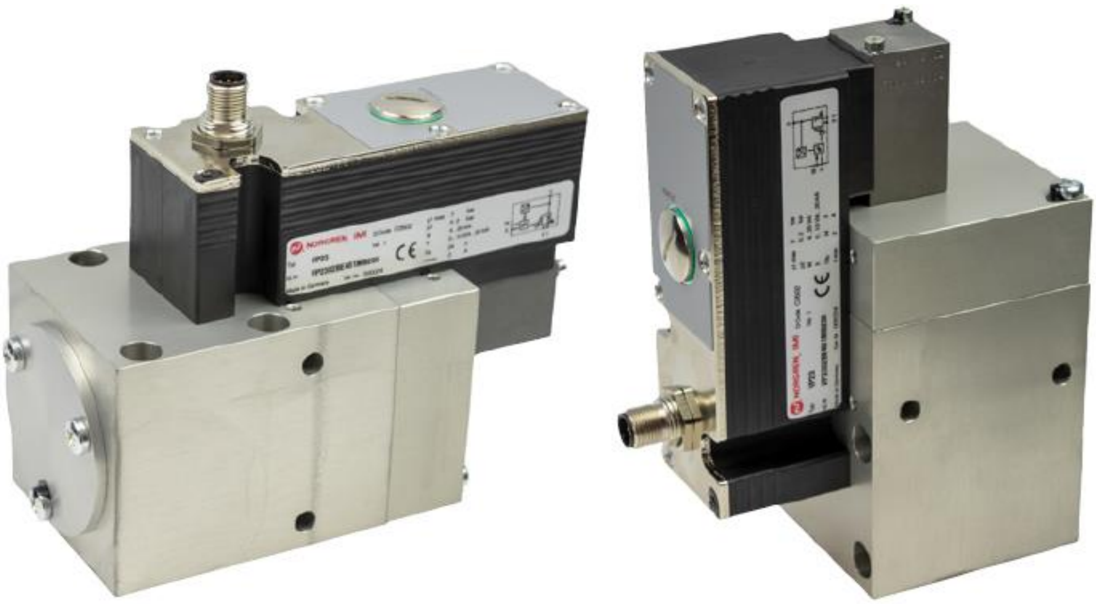


Figure 4.6 – Pressure control valve

4.2.5 FAUDI Aviation AFGUARD

The FAUDI Aviation AFGUARD pictured in Figure 4.7, is a measurement system used to monitor the amount of particulate matter such as free water present in aviation fuel (Attachment 17). The AFGUARD is an electronic water sensor (EWS) designed to detect and quantify small amounts of free water in the fuel. The working principle of the water sensor, illustrated in Figure 4.8, is based on scattered light detection that uses a precisely defined, constant light beam to penetrate the fuel. Scattered light from particulate matter is then reflected and detected by photodiodes in the sensor. This sensor provides real-time water levels in parts per million (ppm), which makes it possible to continually supervise the quality of the jet fuel to ensure the delivery of clean, water free fuel at all times. The EWS meets the requirements of EI 1598 and is accepted by Joint Inspection Group (JIG) and recommended by IATA Fuel Quality Pool (IFQP).

Figure 4.7 – Faudi AFGUARD water sensor

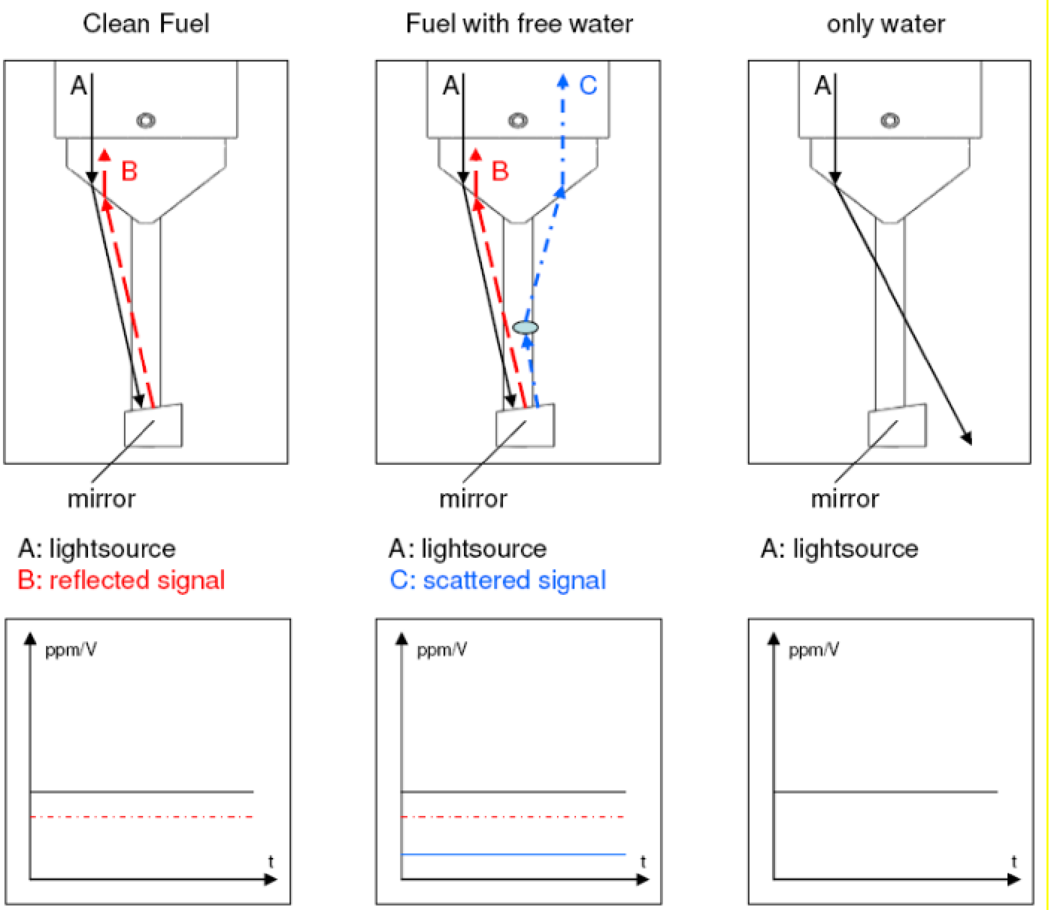


Figure 4.8 – Working principle of the AFGUARD sensor

For the prototype of this aviation refuelling system, the EWS is placed between the outlet of the filter water separators and the inlet of the refuelling unit. This will allow the fuel to pass the sensor in each of the different modes. It is recommended that the AFGUARD is placed downstream in order to also verify filter performance. To prevent a layer of dirt forming on the mirror or optics of the sensor it is important that the EWS is installed in horizontal position.

4.2.6 FAUDI SlugGuard

The FAUDI SlugGuard is an electronic water sensor used to distinguish between aviation fuel and water. (Attachment 18) In the refuelling system, the SlugGuard is installed on the drain outlet of the sample tank bottom for continuous detection of water in the drain point. This is useful for monitoring the fuel of any free water present in the sample tank. The standard design of the SlugGuard, shown in Figure 4.9 is made from stainless steel and qualifies to the EI 1592 specification [41].

Figure 4.9 – SlugGuard

4.2.7 VEGA transmitters

VEGABAR 28

The pressure transmitter (PT) used in the system is the VEGABAR 28 delivered by VEGA (Attachment 19). The VEGABAR 28 is a pressure transmitter with a ceramic measuring cell used for measurement of liquids, gases, and vapours in process systems. In the refuelling system, the transmitter is used for controlling the pressure throughout the process to ensure that the fuel is delivered with a set pressure at all times. If the pressure is too high, or too low, the transmitter will alert an error and shut down the process. This is important to avoid any system malfunction that may damage the equipment. For process pressure measurement of liquids in pipelines, it is important that the transmitter is mounted in a vertical position pointed downwards, as shown in Figure 4.10. The VEGABAR 28 records the measured values with high accuracy and converts it into an electrical signal. The wetted parts of the transmitter are made from stainless steel 316L material.

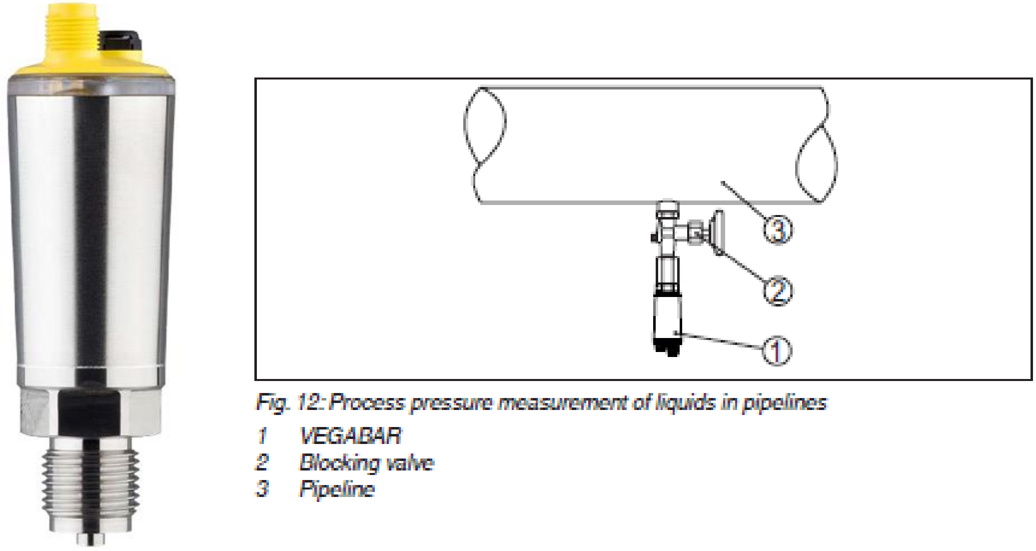


Fig. 12: Process pressure measurement of liquids in pipelines

1 VEGABAR
2 Blocking valve
3 Pipeline

Figure 4.10 – Pressure transmitter

VEGADIF 85

The differential pressure transmitter (PDT) used in the system is the VEGADIF 85 delivered by VEGA (Attachment 20). The VEGADIF 85, shown in Figure 4.11, is used for measurement of liquids, gases, and vapours. One transmitter is installed on top of each filter vessel in the refuelling system for continuous monitoring of the pressure drop across the filters. The transmitter will measure the level of contamination in both filters and alert if the filters are dirty or fouled, so that they can be replaced when necessary. The VEGADIF 85 is using a metallic measuring cell as sensor element that is able to measure extremely small differential pressures that is converted into an output signal. Another benefit of using this transmitter is its high reliability.

Figure 4.11 – Differential pressure transmitter

VEGAPULS 11

The radar level transmitter used in the system is the VEGAPULS 11 delivered by VEGA, pictured in Figure 4.12. The VEGAPULS 11 radar level transmitter is the ideal sensor for non-contact level measurement of liquids in a maintenance-free operation (Attachment 21). This compact radar sensor is used in the refuelling system to monitor the level of fuel in the storage tank and is mounted directly on the fuel tank lid. Radar signals are emitted by the transmitter’s antenna and reflected by the fuel. The fuel level is then analysed and determined by how long it takes from the emitted signal to return to the transmitter. The current loop for the transmitter is a 4-20mA output signal with a measuring range up to 8 meters. The wetted parts of the instrument are made of polyvinylidene fluoride (PVDF).

Figure 4.12 – Radar level transmitter

4.3 Results from process calculations

The results of process calculations made for the final design are presented in Table 4.1, which includes the required flow rate and pressure in the system along with the pipe diameter. These calculations have been made by using the equations and methods that are described in Chapter 3.4. Additionally, the minor losses due to pipe fittings have been found by using and online pressure drop calculator [42]. All the process calculations, parameters, and additional explanations are included in Attachment 22. These calculations have been the vital basis for selecting components and piping for the prototype. Results from the prototype testing are analysed and compared to these process calculations.

Parameter	Value	Unit
Flow rate	225	litre/min
Pressure	2.67	bar
Pressure drop	1.57	bar
Velocity	3.3	m/s
Fuel pipe diameter	1.5	inch

Table 4.1 – Process calculations

4.4 Results from prototype testing

This chapter will describe the results from prototype testing in Imenco’s workshop. The test runs are carried out according to the set up and procedure for testing described in Chapter 3.7. Prior to the planned prototype testing, Imenco discovered a few issues that could affect the outcome of the test runs. Most of these issues were dealt with by the mechanics before the final testing took place and have not disrupted the measuring of pressure and flow during the test runs. These issues are described as follows:

The radar level transmitter (VEGAPULS 11) mounted on the tank lid for measuring fuel level in the storage tank is not working properly. The radio waves are interfered by the tank lid because the transmitter is placed too high up. This makes it challenging to monitor how much fuel is left in the storage tank. Another issue that have been discovered is gas leaking backwards in the system and affecting the pressure. This is happening because the solenoid valves only close in one flow direction, with no obstacle to prevent the gas from leaking through the back of the closed valve. When the gas flows in the wrong direction, it will affect the pressure and flow of the fuel. Therefore, the following results will be from test runs carried out with check valves installed. Table 4.2 presents the pipe dimensioning and measured parameters for the system during testing. The following sections will describe the results from all three test runs of the prototype.

Parameter	Value	Unit
Flow rate	194	litre/min
Pressure	2.2	bar
Fuel pipe diameter	1.5	inch
Sample tubing diameter	20	mm

Table 4.2 – Test results

Test run #1: Fuelling mode

In this test run the fuel is transferred through the system and into a second storage tank. The pressure during the fuelling mode test run is measured at 2.2 bar and remains more or less constant throughout the entire fuelling process. This shows to be somewhat reduced compared to the process calculations and expected pressure of 2.67 bar. Because of the PSV mounted on the storage tank, the system pressure will not be able to exceed 2.2 bar regardless of the set pressure for the PCV. The storage tank PSV will blow out and equalize any pressure that exceeds the set value as a safety measure. The manometer in Figure 4.13 is showing the measured pressure in this test run.

Figure 4.13 – Manometer from testing

The fuelling mode flow rate is measured with a master flow meter mounted on the fuelling hose going into the second storage tank. During this process the flow rate is measured at 194 litre per minute, which is lower than the calculated flow rate of 225 litre per minute. A lower flow rate is expected due to the initial pipe diameter of 1.5" being reduced to 20 mm tubing. Figure 4.14 is showing the measured flow rate on the master flow meter during fuelling.

Figure 4.14 – Master flow meter during testing

Test run #2: Sampling mode

The sampling mode testing runs through the entire sequence of fuel sampling. In this test the pressure is also measured at 2.2 bar and remains more or less constant throughout the sampling sections. The flow rate have not been measured during the sample mode, although it is expected to match the flow rate of the fuelling mode. Due to the settle time being set to just 30 seconds during the test runs, the fuel does not have enough time to settle in order for the SlugGuard to detect any water present in the sample tank. This is not an essential part of the first test runs, as the priority at this stage is to see if the process of moving fuel through the system is working as intended.

When the fuel enters the sample tank, it is impossible to know the level of fuel in the tank. To see how much fuel is accumulated from all three sample sections, a ball valve is mounted on the drain outlet in order to empty the fuel into a bucket. This shows that the sample tank contains around 7-8 litre of fuel, which is a lot more than expected. The reason for this amount of fuel is that the inlet pressure from the PCV is set to 3 bar during sample mode, although this should have been set much lower. If the set time of each section had been higher than 5 seconds in this test run, the sample tank could overflow and allow fuel to leak into the system. The finishing recycle section of the sampling mode is intended to transfer the sampled fuel back into the storage tank. During this test run the fuel is not recycled back through the tubing as there is no valve installed to open the air vent on the storage tank, and therefore no pressure to move the fuel. This results in the recycle tubing not being tested properly, and the sampling mode is not completed as expected.

Test run #3: Emptying the fuel tank

In the final test run the storage tank is emptied by running the fuelling mode until all of the fuel is transferred into the second storage tank. When emptying the storage tank, the master flow meter shows that the flow rate decreases from 201 litre/min to 188 litre/min in four minutes, before dropping to zero when there is no fuel left in the tank. The pressure during this fuelling is also measured at 2.2 bar.

The results from these test runs can be summarised with focus on the measured parameters. During all three test runs the pressure remained somewhat constant at 2.2 bar, while the flow rate is assumed to be more or less stable at 194 litre per minute when measured. These numbers shows to be lower than the results from the process calculations, although this is expected due to the initial pipe diameter being reduced for building the prototype. The results are also affected by several errors that occurred during the test runs in terms of parameters not being measured and some processes not being run through properly.

5. Discussion

In this chapter, the project is summarised and reviewed as a whole. Additionally, all of the results from developing, designing, and testing the prototype are discussed and analysed. Expectations from the project and discoveries throughout the process are compared and reflected on.

This project was based on the idea of developing a compact aviation refuelling system that can move fuel with pressure from nitrogen or dry air in order to remove the requirements of pumps. Initially, the intention was to make this design as compact as possible for the system to be fitted inside a “Blackbox” as housing. Several changes were made on the design as the project progressed, resulting in a change of focus where housing was no longer a priority for the early-stage prototyping. Testing the principle and function of the prototype should be the main priority before moving on to the aesthetics of the design. During the design process and 3D-model assembly of the refuelling system, it proved to be very plausible for the system to eventually be able fit into a “Blackbox” housing. In order to reach this goal in the future, there are several challenges that are important to discuss. The biggest challenge that was discovered during the prototype assembly and installation would be the possibility of changing the filters or other components if the piping is welded. The filters would naturally have to be replaced if they are dirty or fouled, although this was not taken into consideration during the design phase of the system. Initially, flanges on the inlet and outlet ports of the filter vessels were removed from the design to reduce the dimensions of the prototype. The mechanics had to put these flanges back on when building the prototype in order for the system to be disassembled if necessary. For the sake of early-stage prototyping, the size of these flanges will not disrupt the overall design in any visible way due to other components taking up more space in both height and width. This also applies to the check valves which had to be installed during the test runs, in addition to the unions that were installed by the solenoid valves. All of these changes were made by the mechanics for practical reasons that should have been discovered during the design phase. The prototype would still be functioning for test runs even if these changes had not been made, but the possibilities of disassembling the system after testing would turn out to be very challenging due to everything being welded together. Ideally, in further development of the prototype the check valves could be replaced by valve blocks. This would remove the problem of leakage and directional issues within the system.

The original pipelines selected for the design was replaced by tubing because these are easily bent and do not require welding, in addition to being cheaper. Due to a reduced diameter in the tubing, the calculated pipelines from the design were not tested. The tubing also resulted in a reduced flow rate compared to the expected rates from the original pipes, as a decrease in pipe diameter results in a decrease of flow rate. Ideally, the pipelines should have been made as intended from the process calculations, as these show to be very accurate to achieve the desired flow and pressure in the system.

Other minor alterations were made on the design during prototyping due to procurement and practical reasons in order to get the prototype ready for testing within the time limit. The prototype testing was initially supposed to take place in the beginning of May, but the assembling and installation was delayed by a couple of weeks, resulting in the test runs being postponed until the end of the month. Although there was just enough time to do a couple of test runs before the end of this semester, the results are clearly affected by the limited time. Ideally, it would have been beneficial to perform more comprehensive tests in order to analyse the results properly. This would include logging of all data measured from sensors and transmitters during the test runs. The data and test results could then have been presented graphically in terms of tables or graphs for this thesis. This is an important factor worth mentioning because testing was intended to be a great part of this project. Further testing would also allow for the recycle tubing during sample mode to be tested properly by installing the solenoid valve for the storage tank air vent. If there had been more time after the prototype assembly process, the 3D-model and GA drawings could have been updated with the changes from the mechanics during building. Such as the piping being replaced with tubing, and the check valves that were installed. Again, limited time is a great factor in this. Discoveries during the testing that led to several ideas of improvements. The issue of not knowing the level of fuel in the sample tank could be solved by installing a flow meter on the tubing going into the sample tank. A level indicator on the tank could also me an alternative, but not preferrable. During the sampling modes from filter sump and storage tank sump, the fuel will not pass the AFGUARD sensor and therefore it will not be checked for any water. Ideally this could be solved by installing a second AFGUARD sensor on the tubing for the fuel to pass through in all modes. However, this would be too expensive and therefore not an option at this point.

The problem with the radar level transmitter on the storage tank could easily be solved by placing the transmitter further down or use an extended probe so that the radio waves are not disturbed by the tank lid. In order to increase the system pressure, the PSV on the storage tank would have to be replaced and set at a higher value than 2.2 bar. A more likely alternative would be to replace the entire storage tank with a tank that is able to withstand a higher pressure. Another thing worth mentioning is that the nitrogen used in the process will be lost when the tank lid is opened for refuelling of the storage tank. The idea of capturing the nitrogen with the same concept as CO_2 capturing could be a possible solution, although this is quite far-fetched and not beneficial, nor a solution that is available in today’s market.

There are many things to discuss and reflect on in the aftermath of this project. A lot of improvements have to be made for the early-stage prototype can develop into an actual product for use in the industry.

6. Conclusion

The results from prototype testing shows that the process pressure is measured at a more or less constant level of 2.2 bar, along with the flow rate of 194 litre per minute. These values are relatively accurate compared to the process calculations that the design is based on. This is concluded with the project of designing and developing the automated aviation refuelling system being successful. The principle that was tested have been proved. It is entirely possible to use compressed air in order to move fuel instead of pumps. Thus removing the requirement of pump units for onshore and offshore refuelling. Although, the limited design pressure of the fuel tank used in testing means that there is a great risk of damage to the system.

This will potentially change the way of aviation refuelling. A fully automated compact system like this can be used on unmanned onshore and offshore installations. In addition, it is possible to reach out to a much bigger market by easily adapting to other industries or market where fluids or gas needs to be moved. This could even apply to the private yacht market or in use for drones or military operations.

It can be concluded that the project has so far succeeded in developing an aviation refuelling system based on compressed air and not pumps. This changes the rules of the game for an entire refuelling industry, hence the name "The game changer". The new technology could be very cost-effective for companies that depend on helicopters or other aviation. The technology will be able to change the need for the number of manhours around control considerably. The yacht market will also be able to ensure better control over the maintenance of the fuel, as well as the possibility of a compact and discreet design. Remote helicopter fuelling stations will also be able to carry out regular maintenance of the fuel without the presence of personnel. It can be concluded that the product has a great market potential and that the product will simplify their everyday life.

6.1 Further work

The aviation refuelling system is only developed and designed as a prototype of Imenco’s innovative concept of offshore helicopter refuelling. Further work would include improvements based on the results of testing, in addition to make the system even more compact. The aim in the long run is to make this a compact “Blackbox” with the whole process system to fit inside a housing.

Further work in testing would be to properly test the recycle mode with a functioning air vent for the fuel to return to the storage tank as intended. Other plans are to connect all the sensors properly in order to do comprehensive test runs with logging all the data to a computer remotely. This would include running the auto sampling mode for several days. Eventually the tubing will be changed, and all valves will be replaced by a valve block to avoid gas leakage within the system.

References

[1] *Defence Standard for aviation turbine fuel*, DEF STAN 91-91 (Jet A-1), Ministry of Defence.

[2] *Standard Specification for Aviation Turbine Fuels*, ASTM D1655 (Jet A-1), ASTM International.

[3] A. M. Helmenstine, Ph.D. "*What is the most abundant gas in Earth's atmosphere?*" ThoughtCo. https://www.thoughtco.com/most-abundant-gas-in-the-earths-atmosphere-604006 (accessed May, 2022).

[4] NiGen. "*Most common uses of nitrogen in oil and gas industry*." https://nigen.com/common-industrial-uses-of-nitrogen-gas/ (accessed 2022).

[5] Compressed Air & Gas Institute. "*Why do compressed air systems need drying?*" https://www.airbestpractices.com/technology/air-treatment/n2/why-do-compressed-air-systems-need-drying (accessed 2022).

[6] FTC, "Jet fuel filtration," October 2003. [Online]. Available: http://www.ftc-houston.com/wp/wp-content/uploads/Jet-Fuel-Filtration-06-04.pdf

[7] HYDRO-CARBON Filtration & Separation. "*Filter Water Separators*." https://www.hydro-carbon.nl/separation-of-water-from-hydrocarbons/filter-waterseparators-coalescers-separators/ (accessed March, 2022).

[8] Projectmaterials. "*Types of valves used in the oil & gas industry*." https://blog.projectmaterials.com/valves/valves-oil-gas-piping/ (accessed April, 2022).

[9] HardHat Engineer. "*Different types of valves used in piping - A complete guide of pipe valves*." https://hardhatengineer.com/different-types-valves-used-piping/ (accessed March, 2022).

[10] T. Mortenson. "*What is a control valve?*" https://realpars.com/control-valve/ (accessed April, 2022).

[11] Bürkert. "*What is a solenoid valve and how does it work?*" https://www.burkert-usa.com/en/Company-Career/What-s-New/Press/Media/Technical-Reports/Technical-Reports-additional-topics/What-is-a-solenoid-valve-and-how-does-it-work (accessed March, 2022).

[12] Jane Yu. "*9 different types of sensor transmitters*." ElectronicDesign. https://www.electronicdesign.com/technologies/test-measurement/article/21166704/okmarts-9-different-types-of-sensor-transmitters (accessed April, 2022).

[13] Ashlin. "*What are the types of industrial sensors used in the process industry?*" Automation Forum. https://automationforum.co/what-are-the-types-of-industrial-sensors-used-in-the-process-industry/ (accessed March, 2022).

[14] Process Industry Forum. "*How do different types of level measurement devices work?*" https://www.processindustryforum.com/article/different-types-level-measurement-devices-work (accessed May, 2022).

[15] Instrumentation Tools. "*Radar Level Measurement*." https://instrumentationtools.com/radar-level-measurement/ (accessed April, 2022).

[16] K. Cope. "*What is a pressure sensor?*" RealPars. https://realpars.com/pressure-sensor/ (accessed April, 2022).

[17] GMS Instruments. "*What is a pressure transmitter?*" https://gms-instruments.com/blog/what-is-a-pressure-transmitter/ (accessed May, 2022).

[18] Sino-Inst. "*Differential Pressure Transmitters*." https://www.drurylandetheatre.com/differential-pressure-transmitters/ (accessed May 2022).

[19] G. Duranso. "*Differential Pressure Transmitter Explained*." Realpars. https://realpars.com/differential-pressure-transmitter/ (accessed April, 2022).

[20] TWI. "*What is the engineering design process?*" https://www.twi-global.com/technical-knowledge/faqs/engineering-design-process (accessed May, 2022).

[21] Jaycon Systems. "*Rapid prototyping for mechanical engineering & product design*." https://jayconsystems.com/blog/rapid-prototyping-for-mechanical-engineering-and-product-design (accessed May, 2022).

[22] *Standards for offshore helicopter landing areas*, CAP 437, Civil Aviation Authority (CAA), 2021. [Online]. Available: https://publicapps.caa.co.uk/CAP437

[23] *Aircraft Fuelling and Fuel Installation Management*, CAP 748, Civil Aviation Authority (CAA).

[24] Standards Norway. "NORSOK standards." https://www.standard.no/en/sectors/energi-og-klima/petroleum/norsok-standards/ (accessed April, 2022).

[25] *Helicopter deck on offshore installations*, NORSOK standard C-004, Standards Norway, 2004.

[26] *074 Recommended guidelines for helideck manual*, Norwegian Oil and Gas Association, 2019. [Online]. Available: https://www.norskoljeoggass.no/en/working-conditions/retningslinjer/operations/aviatonhelicopter/074-recommended-guidelines-for-helideck-personnel/

[27] *Helideck Manual*, Helicopter operations on offshore installations, Norwegian Oil and Gas Association, 2017.

[28] *Aviation Fuel Supply Standards*, JIG Standards, Joint Inspection Group (JIG). [Online]. Available: https://www.jig.org/standards-publications/

[29] The International Air Transport Association (IATA). "Fuel." https://www.iata.org/en/programs/ops-infra/fuel/ (accessed April, 2022).

[30] The International Air Transport Association. "IATA Fuel Quality Pool (IFQP)." https://www.iata.org/en/programs/safety/audit/ifqp/ (accessed April, 2022).

[31] *EI 1581 Specifications and laboratory qualification procedures for aviation fuel filter/water separators*, 6th edition, Energy Institute, 2016.

[32] *EI 1589 Materials compatibility testing for aviation fuel filter elements and fuel sensing devices*, 1st edition, Energy Institute, 2016.

[33] INTECH GmbH. "*Pipeline design and selection*." https://intech-gmbh.com/pipelines_calc_and_select/ (accessed April, 2022).

[34] I. Banerjee. "Is flow rate constant." Lambda Geeks. https://lambdageeks.com/is-flow-rate-constant/ (accessed April, 2022).

[35] Khan Academy. "*What is volume flow rate?*" https://www.khanacademy.org/science/physics/fluids/fluid-dynamics/a/what-is-volume-flow-rate (accessed March, 2022).

[36] Britannica. "Thermodynamic properties and relations - Equations of state." https://www.britannica.com/science/thermodynamics/Equations-of-state (accessed May, 2022).

[37] Engineering Units. "*Determine compressibility factor - Z factor*." https://engineeringunits.com/compressibility-factor-z-factor/ (accessed April, 2022).

[38] tec-science. "*Pressure loss in pipe systems*." https://www.tec-science.com/mechanics/gases-and-liquids/pressure-loss-in-pipe-systems/ (accessed May, 2022).

[39] R. Sellens Ph.D. "Losses in pipes." Queens University. https://me.queensu.ca/People/Sellens/LossesinPipes.html (accessed April, 2022).

[40] Bright Hub Engineering. "*Use Reynolds number for pipe flow to with whether it is laminar flow or turbulent flow*." https://www.brighthubengineering.com/hydraulics-civil-engineering/55053-pipe-flow-calculations-2-reynolds-number-and-laminar-and-turbulent-flow/ (accessed March, 2022).

[41] *EI 1592 Design, functional requirements and laboratory testing protocols for electronic bulk water detectors for use in aviation fuelling*, 1st edition, Energy Institute, 2017.

[42] Pressure Drop Calculator. http://www.pressure-drop.online/ (accessed March, 2022).

List of attachments

- Included in a separate file.