Design of horizontal pressure vessel: for oxygen gas

A project report

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Executive summery

The aim of our project is to design a pressure vessel based on the given specifications of capacity, operating pressure, maximum and minimum operating temperature, fluid type, material, support, shell, head and orientation.

Thus, design of oxygen pressure vessel should follow some national standards, international codes that provide high safety factor. During operation, the pressure vessel has to withstand several induced stresses due to internal or external pressure. Thus, for the safety purpose storage vessels has to be designed according to ASME standards and rules. Some popular codes which are used for the design of pressure vessel are ASME Boiler and Pressure Vessel Code (1).

it is important to design the fluid storage container such that no leakage can take place as well as the container has to withstand desired pressure and high or low temperature. The pressure vessel will be designed by a CAD software namely Solidworks.

Abbreviations

ASME = American society of mechanical engineers

ASTM = American society for testing and materials

CAD = computer aided design

K = kelvin

°C = degree Celsius

°F = degree Fahrenheit

LOX = liquid oxygen

STP = standard temperature

g/L = gram per liter

PVC = polyvinyl chloride

PSI = pounds per square inch

Kg/m^3 = kilogram per cubic meter

$g.mol^{-1}$ = grams per mol

kJ/mol = kilojoules per mole

% = percent

C = carbon

Mn = Manganese

P = Phosphorus

S = Sulfur

Si = Silicon

Cr = Chromium

Ni = Nickel

GPa = gigapascal

MPa = megapascal

KSI = kilopounds per square inch

Mm =millimeter

in = inch

MAWP = maximum allowable working pressure

BPVC = Boiler and Pressure Vessel Code

QFD = quality function deployment

D_i = inner diameter

D_o = outer diameter

m^3 = cubic meter

σ_h = hoop stress

σ_l = longitudinal stress

ρ = density

V_h= volume of head

V_s = volume of shell

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1. Chapter one Introduction

1.1. Identification of need

The greatest commercial use of oxygen gas is in the steel industry. Large quantities are also used in the manufacture of a wide range of chemicals including nitric acid and hydrogen peroxide. It is also used to make epoxyethane (ethylene oxide), used as antifreeze and to make polyester, and chloroethene, the precursor to PVC. Oxygen gas is used for oxy-acetylene welding and cutting of metals. A growing use is in the treatment of sewage and of effluent from industry.

Oxygen is commonly relied upon in health and medical applications. Liquid oxygen is used as an oxidant for liquid fuels in the propellant systems of missiles and rockets. Oxygen is widely applied in the metal industries in conjunction with acetylene and other fuel gases for metal cutting, welding, scarfing, hardening, cleaning and melting. Steel and iron manufacturers also extensively use oxygen or oxygen-enriched air to affect chemical refining and heating associated with carbon removal and other oxidation reactions. Benefits such as fuel and energy savings plus lower total emission volumes are often achieved when air is enriched or replaced with higher-purity oxygen.

In the chemical and petroleum industries, oxygen is used as a feed component to react with hydrocarbon building blocks to produce chemicals such as alcohols and aldehydes. In many processes, the oxygen for reaction can be obtained from the use of air. The pulp and paper industry uses oxygen as a bleaching and oxidizing agent. A variety of process (liquor) streams show enhanced physical properties after treatment with oxygen; plant operating costs also improve.

Similarly, oxygen enhances the combustion process in industries that manufacture glass, aluminum, copper, gold, lead, and cement, or that are involved in waste incineration or remediation.

Medical oxygen is available in gaseous form in cylinders and in liquid form (kept in cryogenic state, cooled to -297°F (-183°C). Liquid storage is less bulky and less costly than the equivalent capacity of high-pressure gaseous storage. It is a compressed form of oxygen and required to be stored much below -200°C to ensure that the oxygen remains in the liquid form. Because the temperature difference between the liquid medical oxygen stored (product) and the surrounding environment is substantial—even in winters—keeping the liquid oxygen insulated from the surrounding heat is essential. The product also requires special equipment for handling and storage.

Perhaps the best-known medical application of oxygen is in oxygen therapy, where patients who are having trouble breathing are given doses of pure or nearly pure oxygen. Oxygen therapy is often used during surgical procedures, during childbirth, during recovery from heart attacks, and during treatment for infectious diseases. In each case, providing a person with pure oxygen reduces the stress on his or her heart and lungs, speeding the rate of recovery.

Although oxygen itself is chemically stable, is not shock-sensitive, will not decompose, and is not flammable.

1.2. Background research

1.2.1.Summary of technical literature

The pressure vessels (i.e. cylinder or tanks) are used to store fluids under pressure. The fluid being stored may undergo a change of state inside the pressure vessel as in case of steam boilers or it may combine with other reagents as in a chemical plant. The pressure vessels are designed with great care because rupture of pressure vessels means an explosion which may cause loss of life and property. The material of pressure vessels may be brittle such that cast iron or ductile such as mild steel. Vessel failures can be grouped into four major categories, which describe why a vessel failure occurs (2)

Selection of the proper metals in an oxygen system, coupled with good design practice can minimize the hazards of ignition and combustion of the metal. metals are not easily ignited; however, metal particles may ignite easily. When ignited, however, burning metals can cause more damage than burning nonmetals because of their higher flame temperatures and because they usually produce liquid combustion products that spread fires readily (3).

Stainless steels are far more ignition- and bum-resistant than titanium and aluminum alloys and are used extensively in high-pressure oxygen systems. The ignition and burn resistance is about the same for most stainless steels; occasional exceptions exist, such as stainless steel 440C, which ignites and propagates flame less easily than other steels. Few problems are experienced with the use of stainless-steel storage tanks or lines (3).

1.2.2.Pressure vessels

Pressure vessels are leakproof containers and as the name implies, they are designed to store liquid or gas at a pressure or temperature, which is different from the ambient temperature and pressure. They may be of any shape and size ranging from automobile tires, or gas storage tanks, to more sophisticated ones in engineering applications.

Pressure vessels, commonly have the shape of cylinder, sphere, ellipsoid, cone, or a combination of these shapes. Correspondingly they are identified as cylindrical, spherical, ellipsoidal or conical. However, some pressure vessels are named after the type of function that they are required to perform.

Pressure vessels includes the interconnected parts and components, valves, gauges and other fittings up to the first point of connection to the pipework. Pressure vessels consist of some of the important parts like shell, head, nozzle, saddles, skirts, etc.

Pressure vessels play a crucial role in various industries. They help to process, store, or transport gases and liquids under high pressure. These vessels are designed to withstand internal or external pressure and are used in applications ranging from chemical plants and oil refineries to nuclear power plants and aerospace engineering. Pressure vessels are one of the main equipment those widely used in industrial facilities.

Figure 1: pressure vessels (image source https://www.vetroresinasenio.com/wp-content/uploads/2016/06/Serbatoi-a-pressione-Vessel-gallery-2_vetroresinasenio.jpg)

1.3. Classifications of pressure vessels

Pressure vessels can be classified according to their intended service, temperature and pressure, materials and geometry

According to the dimensions.:

- Thin-walled Pressure Vessels: If the wall thickness of the shell (t) is less than 1/10 of the diameter of the shell (d), then it is called a thin wall cylinder. Thin shells are used in boilers, tanks and pipes.
- Thick-walled Pressure Vessel: if the wall thickness of the shell is greater than 1/10 of the diameter of the shell, then it is said to be a thick shell. thick shells are used in high pressure cylinders, tanks, gun barrels etc.

According to the intended use of the pressure vessel:

- storage containers: they are only used for storing fluids under pressure, and in accordance with the service are known as storage tanks. There are a lot of products that require pressure in order to stored properly. Storage pressure vessels fulfill this need and each vessel must be uniquely designed to accommodate a specific type and temperature of product. Examples of product include propane, ammonia, butane, chlorine, and LPG.
- Process vessels: have multiple and varied uses, among them we can mention heat exchangers, reactors, fractionating towers, distillation towers, etc.

based on Shape:

- Cylindrical Pressure Vessels: Cylindrical pressure vessels are one of the most common types. They have a cylindrical shape with flat or dished ends, offering a simple and effective design for containing fluids under pressure. These vessels are used in applications such as storage tanks, air receivers, and hydraulic accumulators.
- Spherical Pressure Vessels: Spherical pressure vessels have a spherical shape, offering excellent pressure distribution and strength. The uniform distribution of stresses allows them to handle higher pressures compared to other shapes. Spherical vessels are typically used in industries dealing with high-pressure gases like LPG storage, petrochemicals, and aerospace.
- Rectangular Pressure Vessels: Rectangular pressure vessels are less common but find their use in specific applications, such as storing compressed gases or liquids in confined spaces. Their design allows for integration into limited spaces where cylindrical or spherical vessels would be impractical.
- Conical Pressure Vessels: A conical pressure vessel is a type of pressure vessel that has a conical shape, with one end resembling a cone. These vessels are commonly used in industries such as food processing, pharmaceuticals, and chemical manufacturing. The conical shape allows for efficient mixing and blending of substances and is often used in processes where controlled agitation, heating, or cooling is required. The conical design promotes the circulation of materials inside the vessel, making it suitable for applications where homogenization and uniform temperature distribution are essential.

based on Construction:

- Welded Pressure Vessels: Welded pressure vessels are constructed by welding together different sections of metal. They are commonly used in applications requiring low to medium pressure and are cost-effective for manufacturing.
- Forged Pressure Vessels: Forged pressure vessels are made from a single piece of metal that is shaped and compressed under high pressure. This manufacturing process provides excellent strength and resistance, making them suitable for high-pressure applications.
- Brazed Pressure Vessels: Brazed pressure vessels are assembled by joining metal parts using brazing techniques. They are often used for applications involving high temperatures and pressures, such as air conditioning and refrigeration.
- Cast Pressure Vessel: A cast pressure vessel is a pressure vessel that is manufactured by casting, a process where molten metal is poured into a mold to achieve the desired shape. Cast pressure vessels are typically made from materials like cast iron, cast steel, or other suitable alloys.
- Riveted Pressure Vessel: A riveted pressure vessel is a type of pressure vessel used to contain fluids or gases under pressure, and it is constructed by joining two or more metal plates or sections together using rivets. Rivets are mechanical fasteners that are inserted through holes in the plates and then deformed or headed on both ends to secure the plates

tightly. Riveted pressure vessels were commonly used in the past but have largely been replaced by welded pressure vessels due to advancements in welding technology. These vessels are characterized by the visible rows of rivet heads on their exteriors.

Based on Positioning/Orientation: Pressure vessels come in various configurations, and one of the primary classifications is based on their positioning/Orientation. Pressure vessels can be categorized as either horizontal or vertical, depending on the orientation of the vessel with respect to the ground. Each orientation offers distinct advantages and is chosen based on specific application requirements and space constraints.

- Horizontal Pressure Vessels: Horizontal pressure vessels are cylindrical tanks laid horizontally, with their length extending parallel to the ground. They typically have dished ends at both sides, providing structural stability and facilitating better stress distribution. The horizontal orientation allows for an even distribution of weight along the vessel's length.
- Vertical Pressure Vessels: Vertical pressure vessels, as the name suggests, stand upright with their height perpendicular to the ground. They often have a cylindrical or spherical shape and can have either flat or dished ends. The vertical orientation allows for better utilization of vertical space, making them suitable for taller installations.

Based on Mounting/Supporting:

- Skirt Mounted Pressure Vessels: These are mainly vertical pressure vessels and they are supported by a skirt at the bottom of the vessel.
- Saddle Mounted Pressure Vessel: Most horizontal pressure vessels are saddle-mounted. Typical examples are shell and tube heat exchangers.
- Leg-Supported Pressure Vessels: Some of the vertical pressure vessels are found to be leg-supported.
- Lug-Supported Pressure Vessels: These types of pressure vessels are mounted on lug supports which are basically plates with holes.

Based on the Method of Heating:

- Fired Pressure Vessel
- Unfired Pressure Vessel

1.3.1. Properties of containing fluid

Oxygen is a chemical element with an atomic number of 8 (it has eight protons in its nucleus). Oxygen forms a molecule (O_2) of two atoms which is a colorless gas at normal temperatures and pressures.

Physical properties

Oxygen condenses at 90.20 K (−182.95 °C, −297.31 °F) and freezes at 54.36 K (−218.79 °C, −361.82 °F). since one liter of liquefied oxygen is equivalent to 840 liters of gaseous oxygen at atmospheric pressure and 20 °C (68 °F)

Oxygen is commonly stored and transported in its liquid form, a form also known as LOX (for liquid oxygen). In the form of LOX, oxygen is used widely as the oxidizing agent in many kinds of rockets and missiles. For example, the huge external fuel tank required to lift the space shuttle into space holds 550,000 liters (145,000 gallons) of liquid oxygen and 1,500,000 liters (390,000 gallons) of liquid hydrogen. When these two elements react in the shuttle's main engines, they provide a maximum thrust of 512,000 pounds.

Atomic number	8
State at 20°C	Gas
Melting point	−218.79°C, −361.82°F, 54.36 K
Boiling point	−182.962°C, −297.332°F, 90.188 K
Freezing Point@ 1 ATM	–218.8°C
Density	1.429 kg/m3 at STP or 1.43 g/L
Critical Pressure	729.1 PSI (49 BAR APPRAX)
Critical Temperature	–118.4°C
Relative atomic mass	15.999 $g.mol^{-1}$
Molecular Weight	31.999
Energy of first ionization	1314 $kJ.mol^{-1}$
Energy of second ionization	3388 $kJ.mol^{-1}$
Energy of third ionization	5300 $kJ.mol^{-1}$
Discovered by	Joseph Priestly in 1774

Table 1: properties of oxygen

1.3.2.Properties of materials selection for vessels construction (tensile stress, yield stress, corrosion resistance, weld ability)

Stainless steel, also known as inox, corrosion-resistant steel (CRES) and rustless steel, is an alloy of iron that is resistant to rusting and corrosion. Stainless steels are iron based alloys containing a minimum of about 10.5% chromium; this forms a protective self-healing oxide film, which is the reason why this group of steels have their characteristic "stainlessness" or corrosion resistance.

stainless steels have five categories:

Austenitic Stainless Steels

This group contain at least 16%chromiumand 6% nickel (the basic grade 304 is sometimes referred to as 18/8) and range through to the high alloy or "super austenitics" such as 904L and 6% molybdenum grades. Additional elements can be added such as molybdenum, titanium or copper, to modify or improve their properties, making them suitable for many critical applications involving high temperature as well as corrosion resistance. This group of steels is also suitable for cryogenic applications because the effect of the nickel content in making the steel austenitic avoids the problems of brittleness at low temperatures, which is a characteristic of other types of steel.

Ferritic Stainless Steels

These are plain chromium (10½ to 29%) grades such as Grades 430 and 409. Their moderate corrosion resistance and poor fabrication properties are improved in the higher alloyed and stabilized grades such as 439 and 444 and in the proprietary grade 3CR12.

Martensitic Stainless Steels

Martensitic stainless steels are also based on the addition of chromium as the major alloying element but with a higher carbon and generally lower chromium content (e.g. 12% in Grades 410 and 416) than the ferritic types; Grade 431 has a chromium content of about 16%, but the microstructure is still martensite despite this high chromium level because this grade also contains 2% nickel

Duplex Stainless Steels

Duplex stainless steels such as 2205 and 2507 (these designations indicate compositions of 22% chromium, 5% nickel and 25% chromium, 7% nickel but both grades contain further minor alloying additions) have microstructures comprising a mixture of austenite and ferrite. Duplex ferritic - austenitic steels combine some of the features of each class: they are resistant to stress corrosion cracking, albeit not quite as resistant as the ferritic steels; their toughness is superior to that of the ferritic steels but inferior to that of the austenitic steels, and their strength is greater than that of the (annealed) austenitic steels, by a factor of about two. In addition, the duplex steels have general corrosion resistances equal to or better than 304 and 316, and in general their pitting corrosion resistances are superior to 316. They suffer reduced toughness below about -50°C and after exposure above 300°C, so are only used between these temperatures.

Precipitation Hardening Stainless Steels

These are chromium and nickel containing steels which can develop very high tensile strengths. The most common grade in this group is "17-4 PH"; also known as Grade 630, with the composition of 17% chromium, 4% nickel, 4% copper and 0.3% niobium. The great advantage of these steels is that they can be supplied in the "solution treated" condition; in this condition the steel is just machinable. Following machining, forming etc. the steel can be hardened by a single, fairly low temperature "ageing" heat treatment which causes no distortion of the component.

Characteristics of Stainless Steels

The characteristics of the broad group of stainless steels can be viewed as compared to the more familiar plain carbon "mild" steels. As a generalization the stainless steels have:

- Higher work hardening rate
- Higher ductility
- Higher strength and hardness
- Higher hot strength
- Higher corrosion resistance
- Higher cryogenic toughness
- Lower magnetic response (austenitic only)

These properties apply particularly to the austenitic family and to varying degrees to other grades and families.

The austenitic stainless steels possess a unique combination of properties which makes them useful at cryogenic (very low) temperatures, such as are encountered in plants handling liquefied gases. These steels at cryogenic temperatures have tensile strengths substantially higher than at ambient temperatures while their toughness is only slightly degraded. Considerable austenitic stainless steel has therefore been used for handling liquefied natural gas at a temperature of -161°C, and in plants for production of liquefied gases. Liquid oxygen has a boiling temperature of -183°C and that of liquid nitrogen is -196°C.

One of the major advantages of the stainless steels, and the austenitic grades in particular, is their ability to be fabricated by all the standard fabrication techniques, in some cases even more severely than the more well-known carbon steels. The common austenitic grades can be folded, bent, cold and hot forged, deep drawn, spun and roll formed. Because of the materials' high strength and very high work hardening rate these operations require more force than for carbon steels, so a heavier machine may be needed, and more allowance may need to be made for spring-back.

Welding: The austenitic grades are all very readily welded. All the usual electric welding processes can be used - Manual Metal Arc (MMAW or "stick"), Gas Tungsten Arc (GTAW or TIG), Gas Metal Arc (GMAW or MIG), Flux Cored (FCAW), Submerged Arc (SAW) and laser.

Type	304L
C	0.03 %
Mn	2%
Cr	18.5%
Ni	9%
P	0.045%
S	0.03%
Si	1%
Density	7900 kg/m³
Elastic Modulus (a) GPa	193

Table 2: chemical properties of selected stainless steel

Note: (a) 1 GPa = 1000 MPa

Material Specification	UNS No	Type/Grade	Tensile Strength		Yield Strength		Minimum Elongation (2 in./ 50mm), %
			ksi	MPa	ksi	MPa	
SA - 240	S30403	304L	81	558	39	269	55

Table 3: mechanical properties of selected stainless steel

1.3.3. General design considerations (Design pressure, temperature and load, material for the vessel, design stress, welded joints, efficiency and corrosion allowance)

Capacity (liter)	5500
Operating pressure (bar)	48
Min. operating temperature	-10
Max. operating temperature	100
Fluid(gas)	Oxygen
orientation	Horizontal
Support	Saddle
material	Stainless steel
shell	cylindrical
Head	Hemispherical

Table 4: design considerations

Material subject to stress due to pressure shall come from ASME Boiler and Pressure Vessel Code SECTION VIII Rules for Construction of Pressure Vessels (4).

The material to be used is 304L stainless steel. The maximum allowable stress value is the maximum unit stress permitted in a given material used in a vessel. The maximum and minimum design temperatures for a vessel will determine the maximum allowable stress value permitted for the material to be used in the fabrication of the vessel. The design pressure for a vessel is called its “maximum allowable working pressure” (MAWP) or “working pressure”.

Each element of a pressure vessel shall be designed for at least the most severe condition of coincident pressure (including coincident static head in the operating position) and temperature expected in normal operation. For this condition, the maximum difference in pressure between the inside and outside of a vessel, or between any two chambers of a combination unit, shall be considered.

the maximum temperature used in design shall be not less than the mean metal temperature (through the thickness) expected under operating conditions for the part considered.

For stainless steel we will use corrosion allowance of 3 mm.

Design Loads: The forces that influence pressure vessel design are internal/external pressure; dead loads due to the weight of the vessel and contents; external loads from piping and attachments, wind, and earthquakes; operating-type loads such as vibration

Welded Joint Efficiency E is influenced by the kind of junction and the welding technique. They are joints that are welded together to make the pressure vessel. It is tested by Radiography.

1.4. Codes, Standards and Regulations

the code that is the most internationally recognized and the most used is Section VIII "Pressure Vessels" part of the Boiler and Pressure Vessel Code (BPVC) of the American Society of Mechanical Engineers (ASME).
Other than the code above, the most commonly used standards for pressure vessels are:

- Europe: EN-13445
- Germany: A. D. Merkblatt
- United Kingdom: British Standards BS 5500
- France: CODAP
- China: GB-150

Rules for pressure vessels for general applications are contained in Section VIII which is the Section of primary relevance for vessels.

Section VIII of ASME Code:

This Section contains the rules for the design, fabrication, inspection, and testing of pressure vessels for general application and covers the following features and items:

- List of acceptable materials,
- Allowable design stresses for the listed materials,
- Design rules and acceptable design details,
- Acceptable forming, welding, and other fabrication methods,
- Bolting materials and design,
- Inspection and testing requirements, and
- Requirements for pressure relief devices.

	Code	Authority
USA	ASME Boiler & Pressure Vessel Code	ASME
U. K	BS 5500 Unfired Fusin Welded Pressure Vessels	British Standard Institute
Germany	AD Merblatter	Arbeitsgemeinschaft Druckbehalter
INDIA	IS 2825	Bureau of Indian Standards
CANADA	CSA B51	Canadian Standard Association

Table 5: pressure vessel codes

The ASME BVPC code is a set of standards, specifications, and design rules based on many years of experience, all applied to the design, fabrication, installation, inspection, and certification of pressure vessels. It was created in the United States of America; several insurance companies demanded a design code in order to reduce losses and casualties. The ASME Boiler and Pressure Vessel is divided into the following sections:

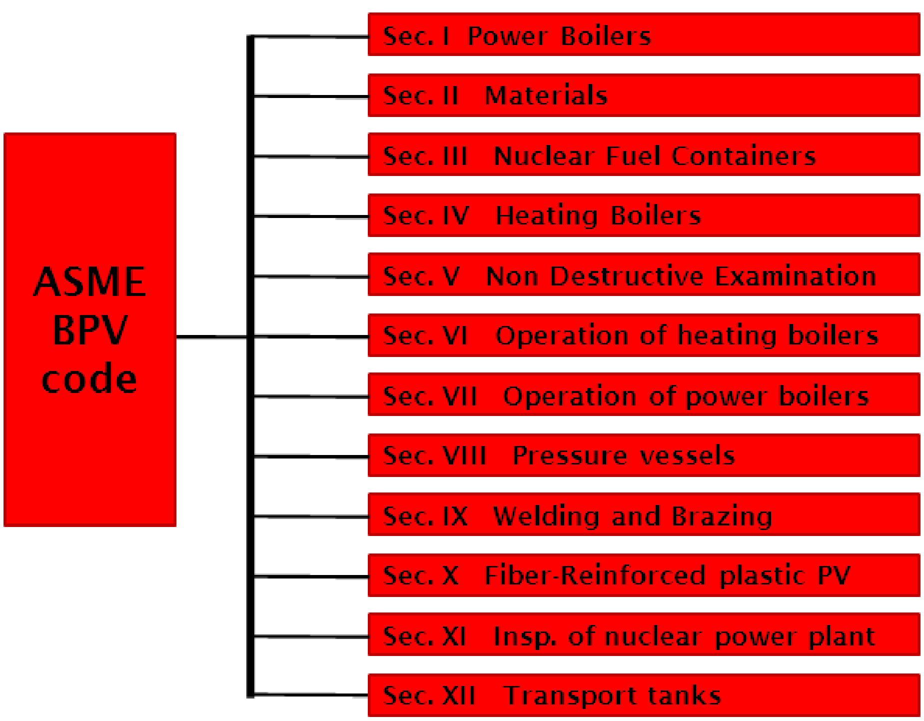

Figure 2: twelve sections of the code

Section VIII, division 1 is organized and divided in sections and parts shown in figure below

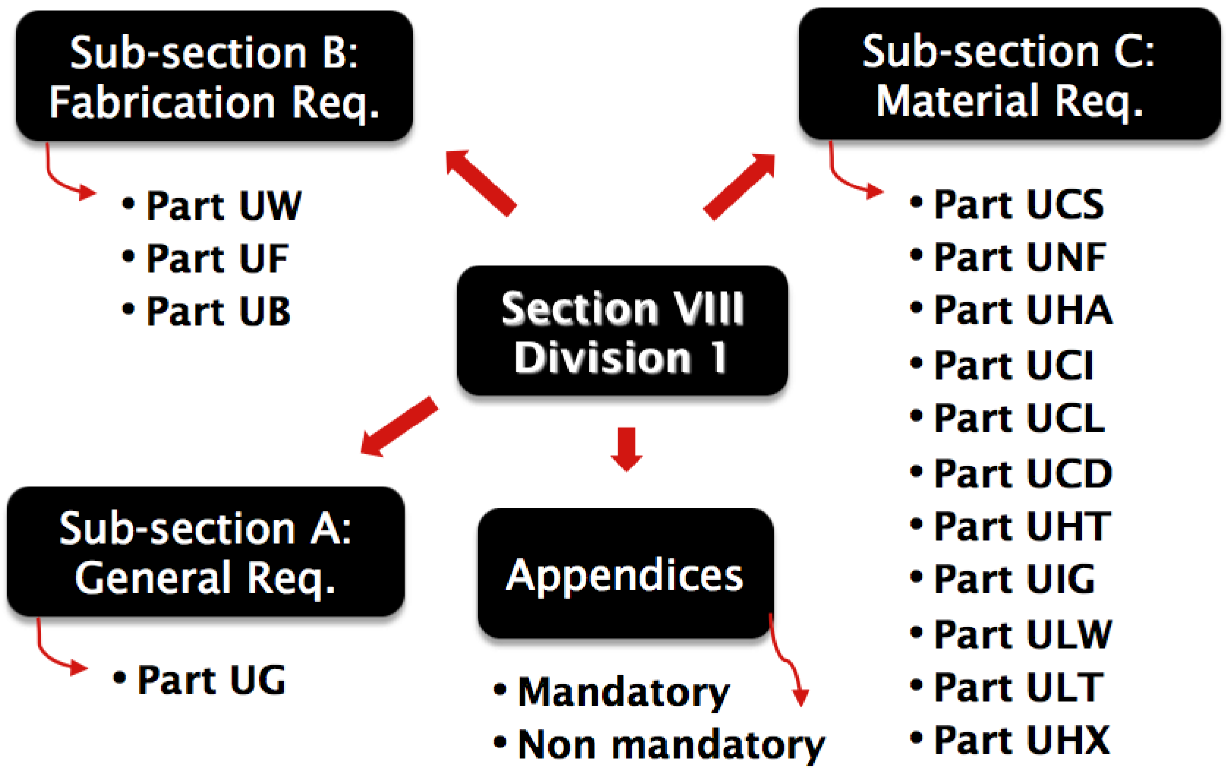

Figure 3: code organization

1.5. Definition of the problem/ Goal Statement

1.5.1.Problem Statement

reactivity of oxygen increases with increasing pressure, temperature, and concentration. In Most materials, such as metals and nonmetals, are flammable in high-pressure oxygen; in which, systems must be designed to minimize ignition and hazards that comes with it. Implementation of successful design, development, and operation of high-pressure oxygen pressure vessels systems requires special knowledge and understanding of material properties, design practices, found in Boiler and Pressure Vessel Code (BPVC) of the American Society of Mechanical Engineers (ASME).

1.5.2.quality function deployment

Quality Function Deployment (QFD) is a structured approach to defining customer needs or requirements and translating them into specific plans to produce products to meet those needs.

QDF uses techniques to design and construct pressure vessels while improving quality and safety of pressure vessels. QDF can be used to guarantee that the design of oxygen pressure vessel has achieved its goal of customer requirements, while also ensuring its engineering performance.

1.6. Objective of the Project

The objective of this report is to design a horizontal oxygen pressure vessel based on the Boiler and Pressure Vessel Code (BPVC) of the American Society of Mechanical Engineers (ASME), following Rules of pressure vessels for general applications contained in Section VIII which is the Section of primary relevance for vessels, while using the given specifications of capacity, operating pressure, fluid type, material etc.

1.7. Performance specifications

The system performance is evaluated based on the pressure vessels capacity to carry out the task for which it was initially developed for.

1.7.1.Define what the system must do

The system has to carry a capacity of 5500L of oxygen, having an operating pressure of 48bar.

The system has to operate at a minimum temperature of -10 Celsius and maximum temperature of 100 Celsius.

2. Chapter two Concept Design Development

2.1. Design Process and Considerations

The design process in pressure vessels has some steps and considerations, the steps are listed below:

I. List or identify the design specifications of pressure vessel.
II. Select an international code.
III. Select material suitable for production of pressure vessels, which shall come from ASME Boiler and Pressure Vessel Code SECTION VIII Rules for Construction of Pressure Vessels (4)
IV. Determine weld type and weld efficiency
V. Identify the diameter, length, size of the pressure vessel.
VI. Design shell based on given specification which is cylindrical in our case.
VII. Design head
VIII. Select the type of support to be used and design it
IX. Identify wall thickness of nozzle
X. Design manhole
XI. Design and draw pressure vessel by using CAD software such as Solidworks.

2.2. Design Specification/ Requirement List

- ✓ Material: Stainless steel
- ✓ Fluid(gas): Oxygen
- ✓ Support: Saddle
- ✓ Capacity (liter): 5500
- ✓ Operating pressure (bar): 48
- ✓ Min. operating temperature: -10
- ✓ Max. operating temperature: 100
- ✓ Orientation: Horizontal
- ✓ Shell: cylindrical
- ✓ Head: Hemispherical
- ✓ Corrosion allowance = 3mm

2.3. Concept Models

2.3.1.Function structure

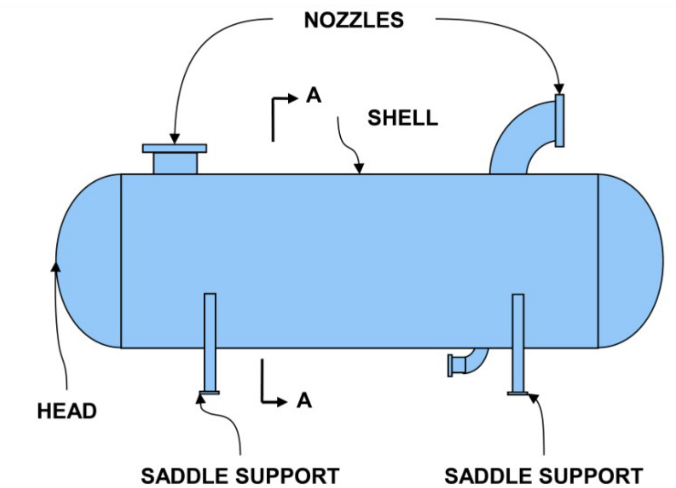

Figure 4: parts of pressure vessel

Shell: The Shell is made of plates that have been joined by an axis during welding and holds the pressure. Shells are either Cylindrical, spherical or conical in shape

Head: this forms the end closure parts of the vessel. Their curvy feature makes the head stronger, thinner, lighter, and thus less costly.

Nozzle: it facilitates the flow of contents into and out of the vessel as well as the attachment of instruments.

Support: is the part that provides a base for holding up the weight of the pressure vessel

Figure 5: saddle support

Flanges: is a flat, circular disc with evenly space holes around its circumference. Used to connect pipes, valves, or other equipment to form a piping system.

Manhole: Manholes are openings used for vessel inspection while they are in service. They are also used for routine maintenance like painting if rust develops or for cleaning and inspection if there is unwelcome dust inside the vessel.

2.4. Selected Concepts

2.4.1.Design objectives, key features of a solution

Designing a horizontal oxygen pressure vessel in accordance with the ASME code requirements, considering the specific characteristics and parameters of oxygen storage applications. Determining the optimum wall thickness of pressure vessel to ensure acceptable maximum stresses while considering the permissible pressures.

To address the hazards associated with the design and manufacture of pressure vessels used for storing oxygen. The construction of more oxygen pressure vessels necessitates the implementation of safer pressure vessels to mitigate risks such as explosions and leakage.

2.4.2.Alternative design concepts for achieving the goal

To design a horizontal oxygen pressure vessel in accordance with ASME Boiler and Pressure Vessel Code SECTION VIII Rules for Construction of Pressure Vessels (5) capable of safely storing oxygen.

2.4.3.Evaluation and comparison of competing design concepts

In our project, we use some factors when evaluating competing design of our pressure vessel. These factors we consider

3. Chapter three Analysis and Results Discussion

3.1. Functional Description

functional description of an oxygen pressure vessel design must ensure that it is safe, efficient, and reliable for storing and transporting oxygen gas at high pressure.

The pressure vessel must be designed based on ASME boiler and pressure vessel code so it can withstand internal pressure and external loads. The pressure vessel must have safety features to prevent over-pressurization and failure. The pressure vessel must be regularly inspected and maintained to ensure its continued safety and reliability.

The material selected must be suitable for the oxygen pressure vessel, the material is high alloy steel or stainless steel which is commonly used for oxygen pressure vessel.

3.2. Material Selection

For this report we have chosen austenitic stainless-steel grade 304L. Grade 304 stainless steel is the most versatile and the most widely used of all stainless steels. Its chemical composition, mechanical properties, weldability and corrosion resistance provide the best all-round performance stainless steel at relatively low cost. It also has excellent low temperature properties.

3.3. Mathematical Modelling and Supporting Analysis

3.3.1. Use of Design Equations and Formulas of for Design of different Components of the Pressure Vessel

Design pressure

Setting Maximum Allowable Working Pressures

Operating Pressure	Minimum Differential Between Operating Pressure and MAWP
Less than 50 psig	10 psi
51–250 psig	25 psi
251–500 psig	10% of maximum operating pressure
501–1000 psig	50 psi
1001 psig and higher	5% of maximum operating pressure

Vessels with high-pressure safety sensors have an additional 5% or 5 psi, whichever is greater to the minimum differential.

Figure 5: setting maximum allowable working pressure

Given value: operating pressure = 48bar

48bar = 696.192psi

Maximum allowable working pressure (MAWP) = operating pressure + minimum differential

= 696.192 + 50

MAWP = 746.192Psi ≅ 51.447bar = 5.145Mpa

Shell design

Length and diameter of shell

The length to diameter ratio of the shell can be found from the standard using the MAWP value we got above.

Pressure	L/D_i standard
0-250	3
251- 500	4
501 and above	5

Table 6: length to diameter ratio

746.192Psi is above 501 therefore $\frac{L}{D} = 5$

L = $5D_i$

Volume of cylindrical shell = $V_s = \frac{\pi D_i^2 \mathrm{L}}{4}$

Substitute L =- $5D_i$

$V_s = \frac{\pi D_i^2 (5D_i)}{4}$

$V_s = \pi D_i^3$

Volume of cylindrical head = $V_h = \frac{\pi D_i^3 [3(\frac{h}{D_i})^2 - 2(\frac{h}{D_i})^3]}{12}$

As working fluid is gas, h = D_i therefore the equation becomes:

$V_h = \frac{\pi D_i^3}{12}$

From ASME

$V_h = \frac{\pi D_i^3}{12} C$, where C = 0.5

$V_h = \frac{\pi D_i^3}{24}$

Total Volume = $2V_h + V_s$

$V_T = 2\frac{\pi D_i^3}{24} + \pi D_i^3$

Simplifying gives us:

$V_T = \frac{13\pi D_i^3}{12}$

Rearranging to find D_i:

$D_i^3 = \frac{12V_T}{13\pi}$

$D_i = \sqrt[3]{\frac{12V_T}{13\pi}}$, where V_T = 5500L = 5.5m^3

$D_i = \sqrt[3]{\frac{12(5.5)}{13(3.14)}}$

D_i = 1.1737m = 1,173.7mm

To find length:

L = $5D_i$

L = 5(1173.7)

L = 5,868.5mm

To determine whether its thin or thick:

MAWP = 0.385SE

Where: S = allowable stress = 16,700psi = 115.14Mpa

E = efficiency = 1

5.145Mpa = 0.385*115.14*1

5.145Mpa ≠ 44.33Mpa

5.145Mpa < 44.33Mpa

Therefore, the shell is thin type based on ASME

Thickness of shell equation for thin wall:

t = $\frac{PR}{SE-0.6P}$

Where, R = $\frac{D_i}{2}$

R = $\frac{1,173.7}{2}$

R = 586.85mm

t = $\frac{5.145(586.85)}{115.14(1)-0.6(5.145)}$

t = 26.95mm

corrosion allowance = C = 3mm

t_s = t + C

t_s = 26.95 + 3

t_s = 29.95mm = 30mm

D_o = D_i + $2t_s$

D_o = 1,173.7 + (2*29.95)

D_o = 1233.6mm

Effective radius = R_{effe} = $\frac{D_o}{2}$

R_{effe} = $\frac{1233.6}{2}$

R_{effe} = 616.8mm

Head design

Thickness of hemispherical heads:

t = $\frac{PR}{2SE-0.2P}$

t = $\frac{5.145(586.85)}{(2)115.14(1)-0.2(5.145)}$

t = 13.17mm

considering corrosion allowance:

t = 13.17 + 3

t = 16.17mm

for safety reasons we will select a thickness of maximum value we got from head and shell which is 30mm. we will use 30mm for both head and shell thickness.

design of manhole

assume diameter of manhole = 500mm

length of manhole = 400mm

$t_{rm} = \frac{PR_m}{SE - 0.6P}$

Where, R_m = radius of manhole = 250mm

$t_{rm} = \frac{5.145(250)}{115.14(1) - 0.6(5.145)}$

t_{rm} = 11.48mm

$t_m = t_{rm}$ + C

t_m = 11.48 + 3

t_m = 14.48mm

Design of nozzle

Assume: outer diameter = D_0 = 200mm

Inlet diameter = D_i = 185mm

Thickness of nozzle = $t_n = \frac{PR_n}{SE - 0.6P}$ + C

$t_n = \frac{5.145(100)}{115.14(1) - 0.6(5.145)} + 3$

t_n = 7.59mm

Internal length = $l_{in} = 2t_n$

l_{in} = 2*3.67

l_{in} = 7.35mm

External Length of nozzle = 150mm (preference)

Weight analysis of each part

Density of 304L = 7900 kg/m^3

Weight of shell:

$V_s = \frac{\pi(D_o^2 - D_i^2)L}{4}$

$V_s = \frac{\pi(1.233^2 - 1.173^2)5.868}{4}$

$V_s = 0.66$ m³

$W_s = \rho V_s g$

W_s = 7900*0.66*9.8

W_s = 51,097.2N

Weight of head:

$V_h = \frac{\pi(D_o^3 - D_i^3)}{12}$

$V_h = \frac{\pi(1.233^3 - 1.173^3)}{12}$

$V_h = 0.068$ m³

$W_h = \rho V_s g$

W_h = 7900*0.068*9.8

W_h = 5,278.3N

Weight of nozzle:

$V_n = \frac{\pi(D_o^2 - D_i^2)L}{4}$

$V_n = \frac{\pi(1.233^2 - 1.173^2)0.157}{4}$

$V_n = 0.03$ m³

$W_n = \rho V_s g$

W_n = 7900*0.03*9.8

W_n = 2322.6N

Weight of manhole:

$V_m = \frac{\pi(D_o^2 - D_i^2)L}{4}$

$V_m = \frac{\pi(1.233^2 - 1.173^2)0.4}{4}$

$V_m = 0.08$ m³

$W_m = \rho V_s g$

W_m = 7900*0.08*9.8

W_m = 6193.6N

Weight of fluid:

$W_f = \rho V_s g$

W_f = 1.429*5.5*9.8

W_f = 77N

Overall weight:

$W_{overall} = W_s + W_h + 2W_n + W_m + W_f$

$W_{overall}$ = 51,097.2 + 5,278.3 + (2)2322.6 + 6193.6 + 77

$W_{overall}$ = 67,291.3N = 6,859.46kg

3.3.2. Assumptions made, making sure to justify your design decisions.

These assumptions are made to simplify the calculations involved in the design of a pressure vessel and to ensure that the vessel can withstand the expected operating conditions safely and efficiently. However, it is important to note that these assumptions may not accurately reflect the actual operating conditions, and additional safety measures may be required to ensure the safety of the pressure vessel.

Assumptions made are manhole diameter, length of manhole, diameter of nozzle.

3.3.3. Supporting Analysis

Stress analysis: to evaluate strength of pressure vessel and determine whether it can withstand the stress and pressure that it will encounter while operating.

Hoop stress (σ_h):

$\sigma_h = \frac{PD_i}{2t_s}$

$\sigma_h = \frac{5.145(1173.7)}{2(29.95)}$

σ_h = 100.81Mpa

Longitudinal stress (σ_l):

$\sigma_l = \frac{PD_i}{4t_s}$

σ_l = 50.41Mpa

Resultant stress:

$\sigma_R = \sqrt{\sigma_h^2 - \sigma_h \, \sigma_l + \sigma_l^2}$

$\sigma_R = \sqrt{100.81^2 - (100.81 * 50.41) + 50.41^2}$

$\sigma_R = \sqrt{7{,}621.99}$

σ_R = 87.3Mpa

3.3.4.Material selection

materials have to be selected based on analyzing the chemical properties and physical properties of materials for appropriate manufacturing materials under reasonable cost control. Material we selected is 304L which has higher work hardening rate, Higher ductility, Higher strength and hardness.

Compared to others stainless steel 304L has better corrosion resistance due to its high chromium content.

3.3.5.Manufacturing plan

Manufacturing plan is going to be using welding process for construction. Manufacturing plan need to consider heat treatment, forming, brazing and assembly.

3.3.6.Safety Maintenance and repair

Increase awareness for staff members to get a complete briefing on contents of each pressure vessel. And also it is important to have an emergency response plan should be in place in case of any accidents.

3.3.7.Cost Analysis

Cost analysis includes Material cost, Fabrication cost, Design cost, Test cost, labor costs, equipment costs

It is important to note that the cost of the pressure vessel is just one aspect of the overall cost of the project. Other costs, such as transportation, installation, and commissioning, should also be considered when estimating the total project cost. Additionally, the cost of maintaining and repairing the pressure vessel over its lifespan should also be factored into the overall cost analysis.

4. Chapter four detailed design

4.1. Part drawings and detailed drawings

Shell

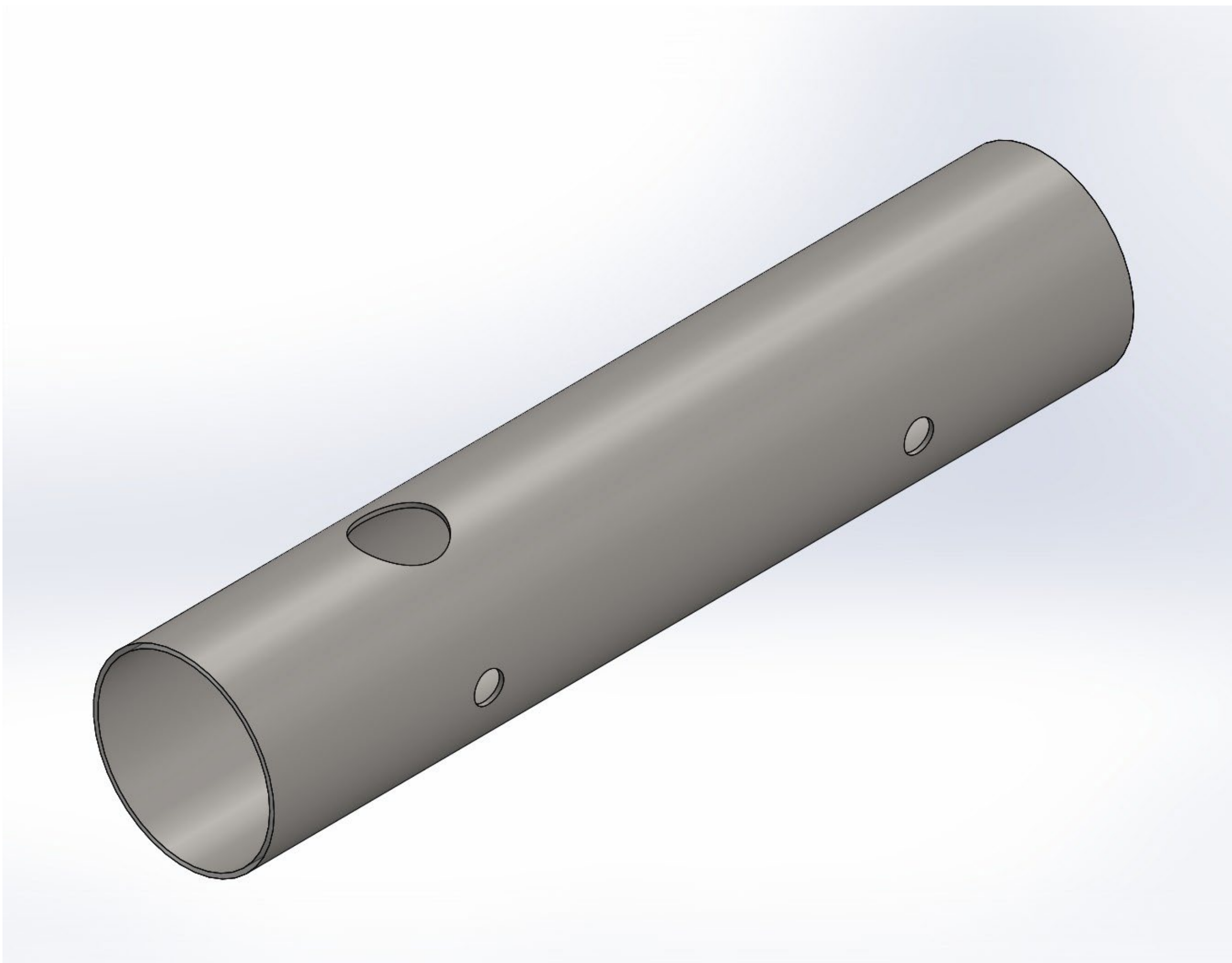

Figure 6: shell part solidworks design

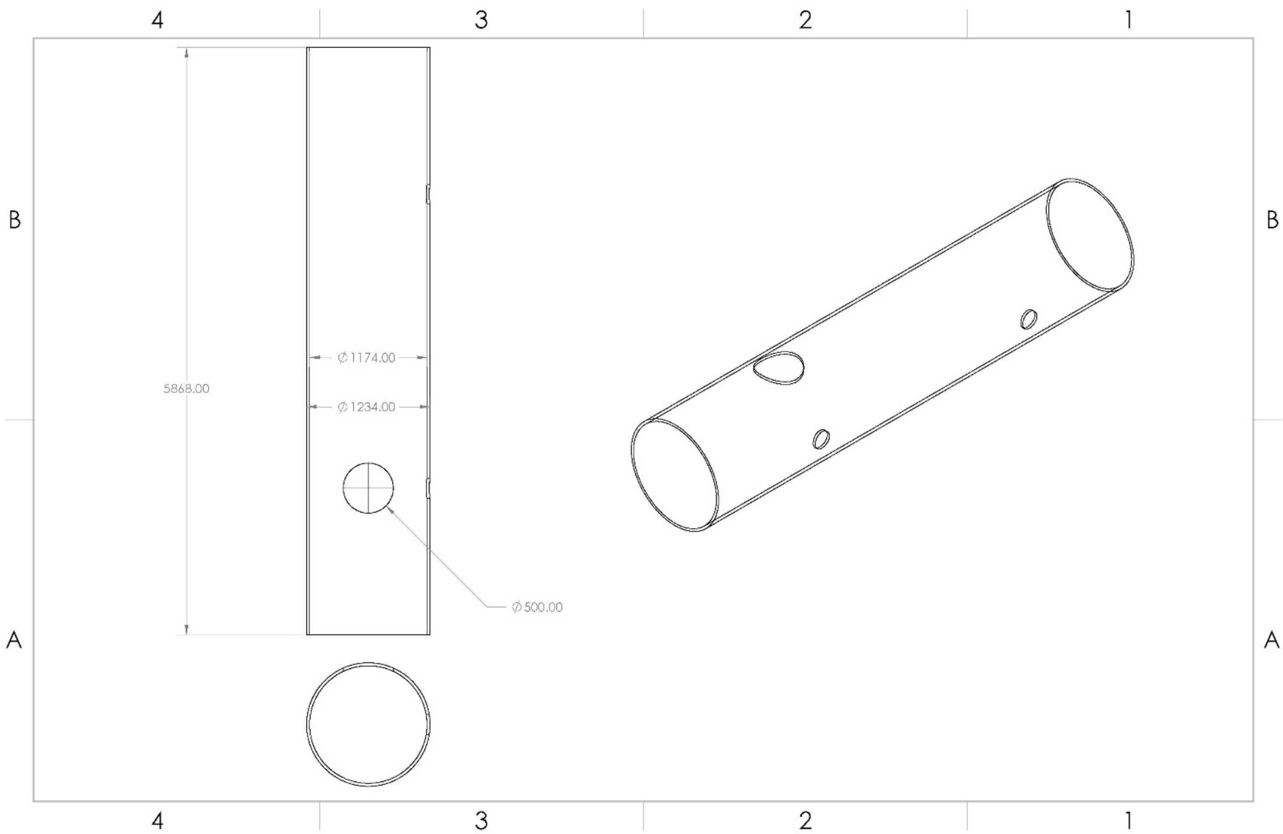

Figure 7: shell drawing

Head

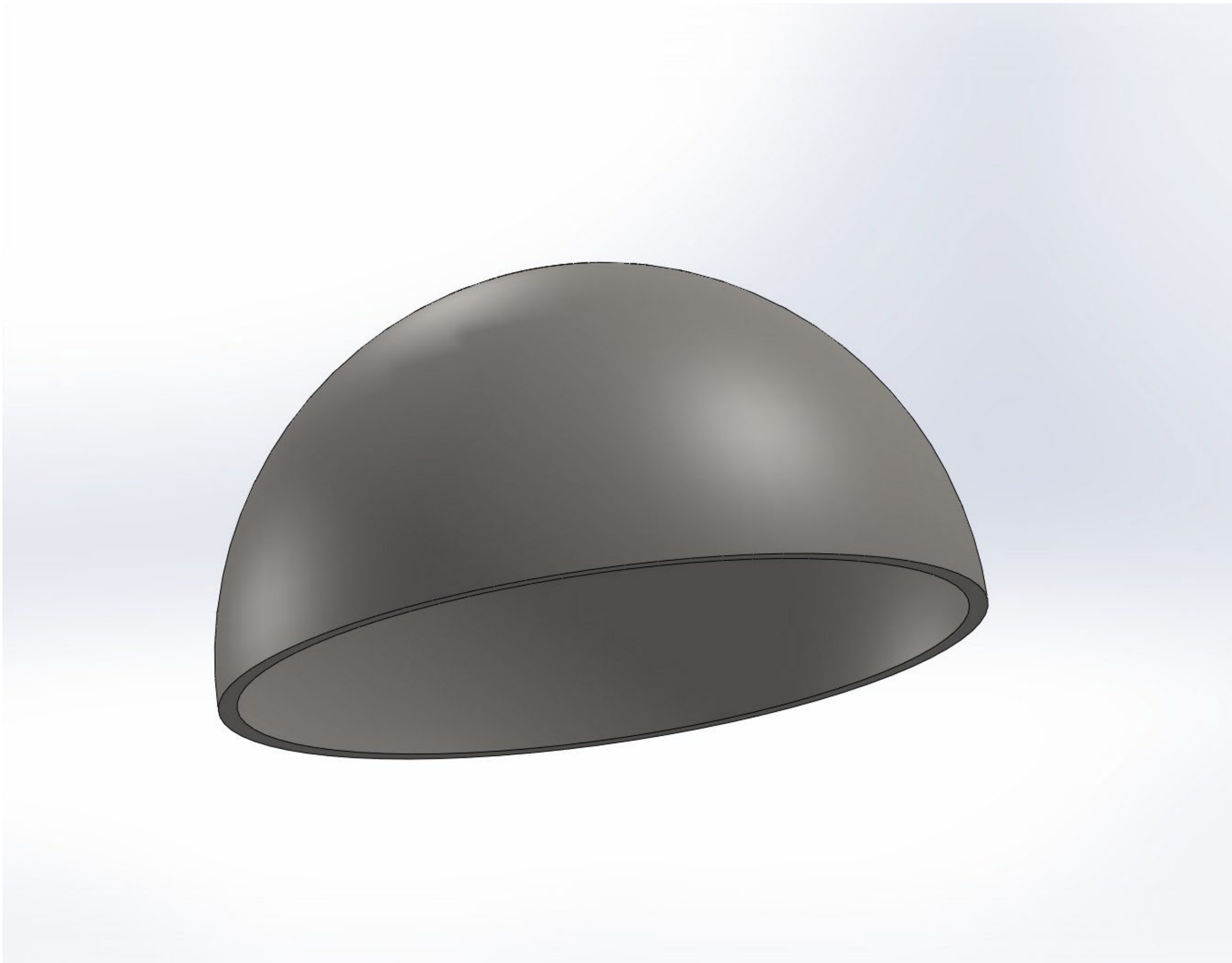

Figure 8: head part solidworks design

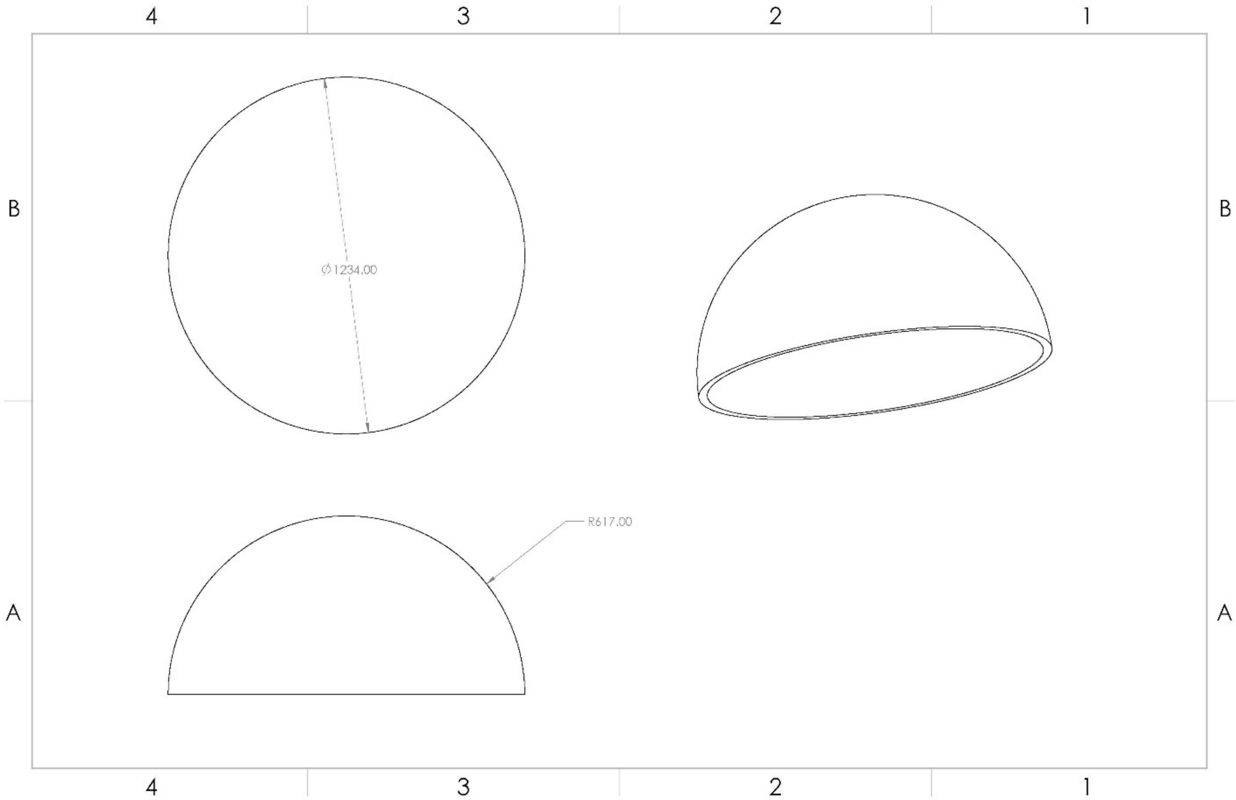

Figure 9: head drawing

Manhole

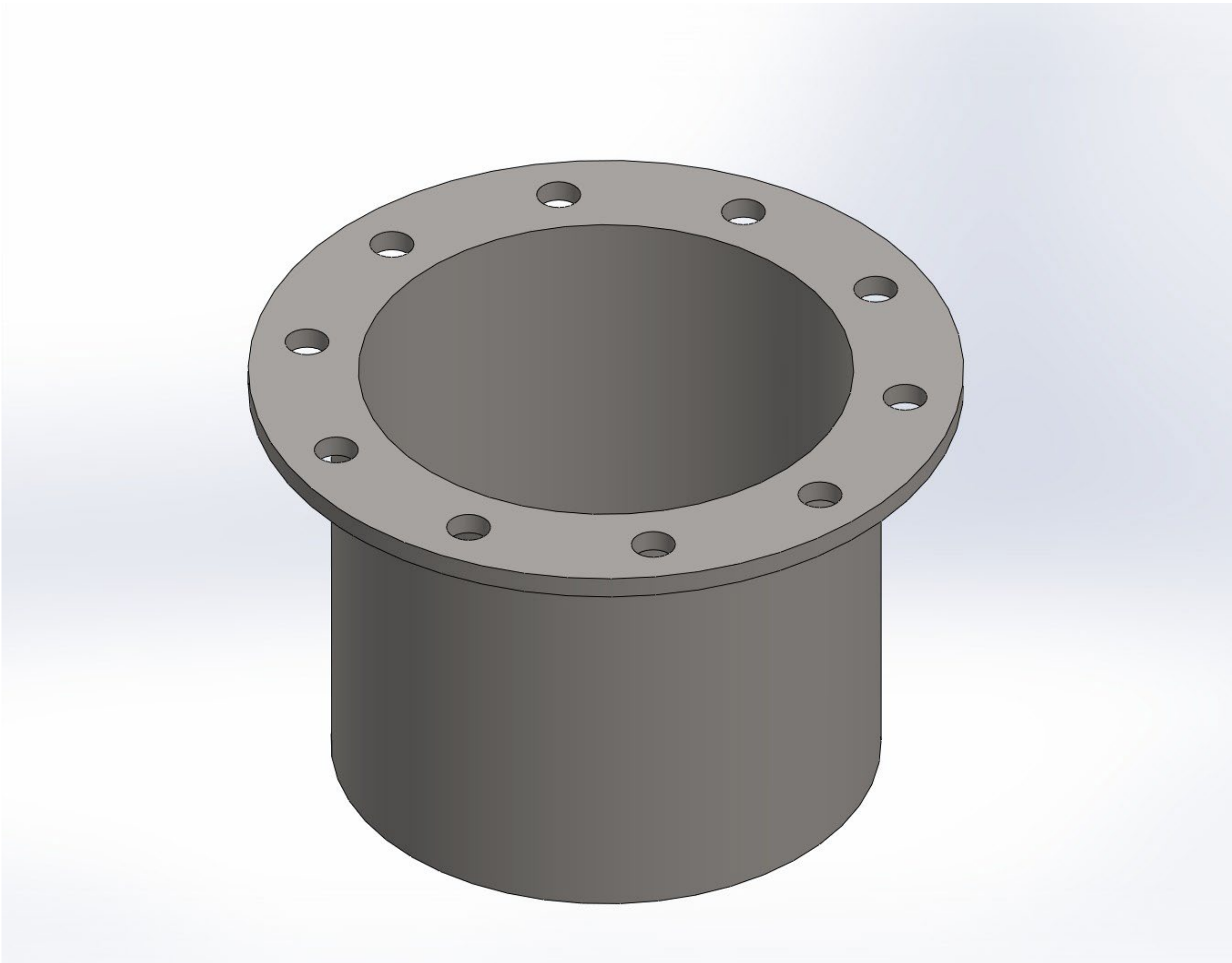

Figure 10: manhole part solidworks design

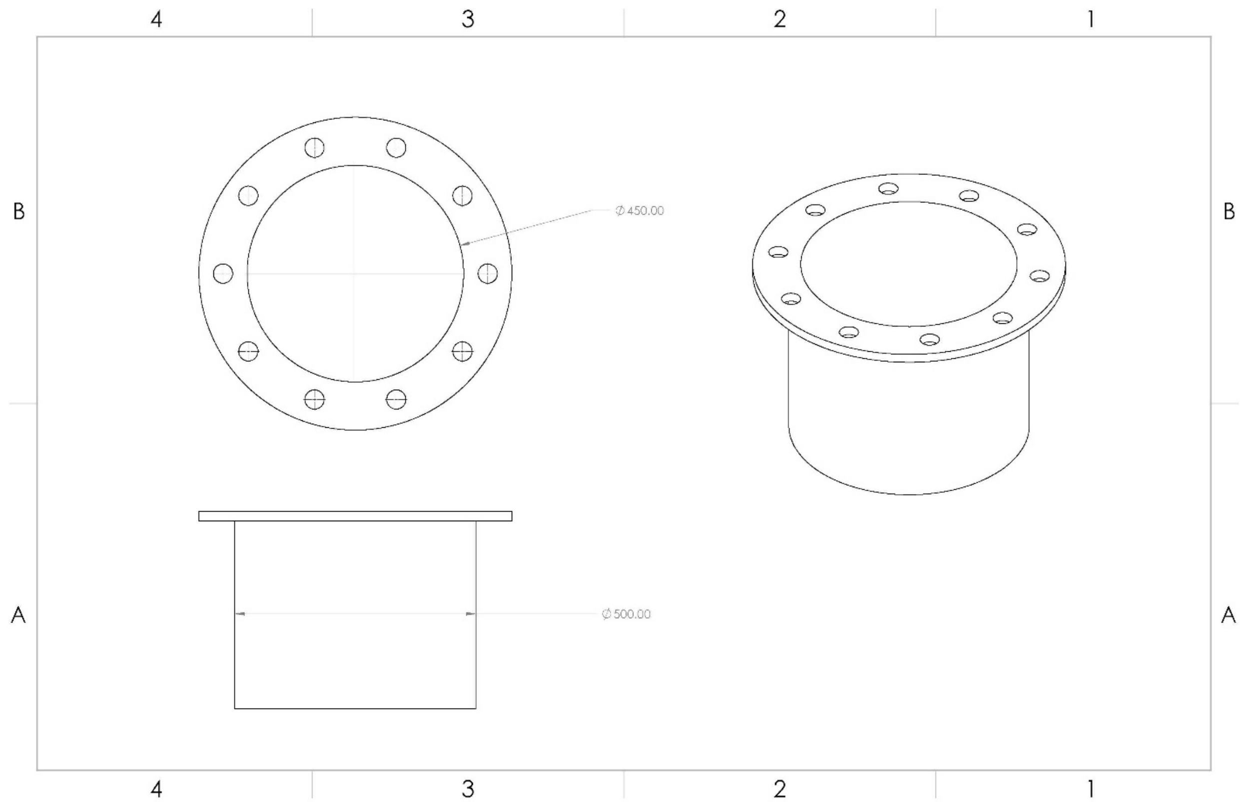

Figure 11: manhole drawing

Nozzle

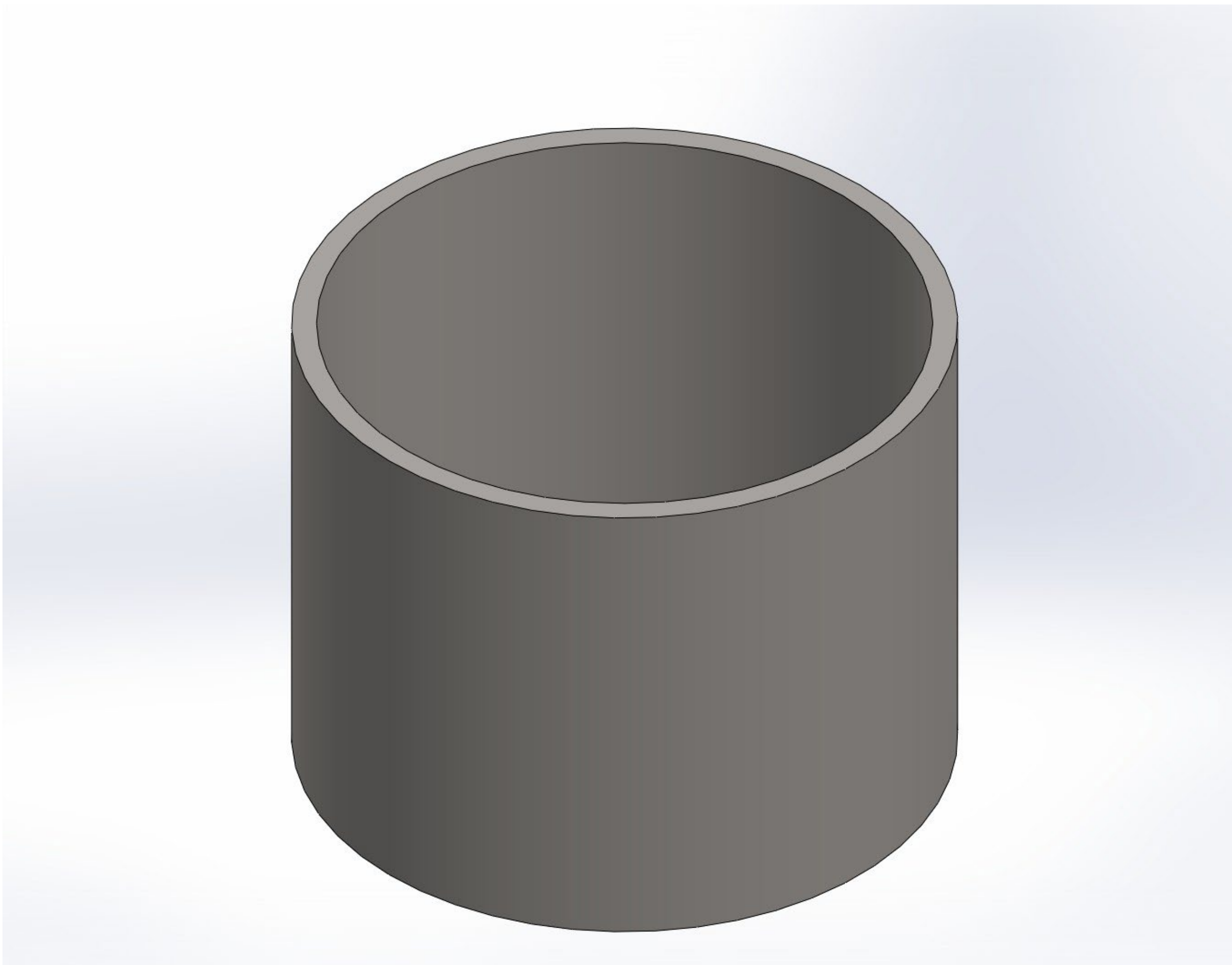

Figure 12: nozzle part solidworks design

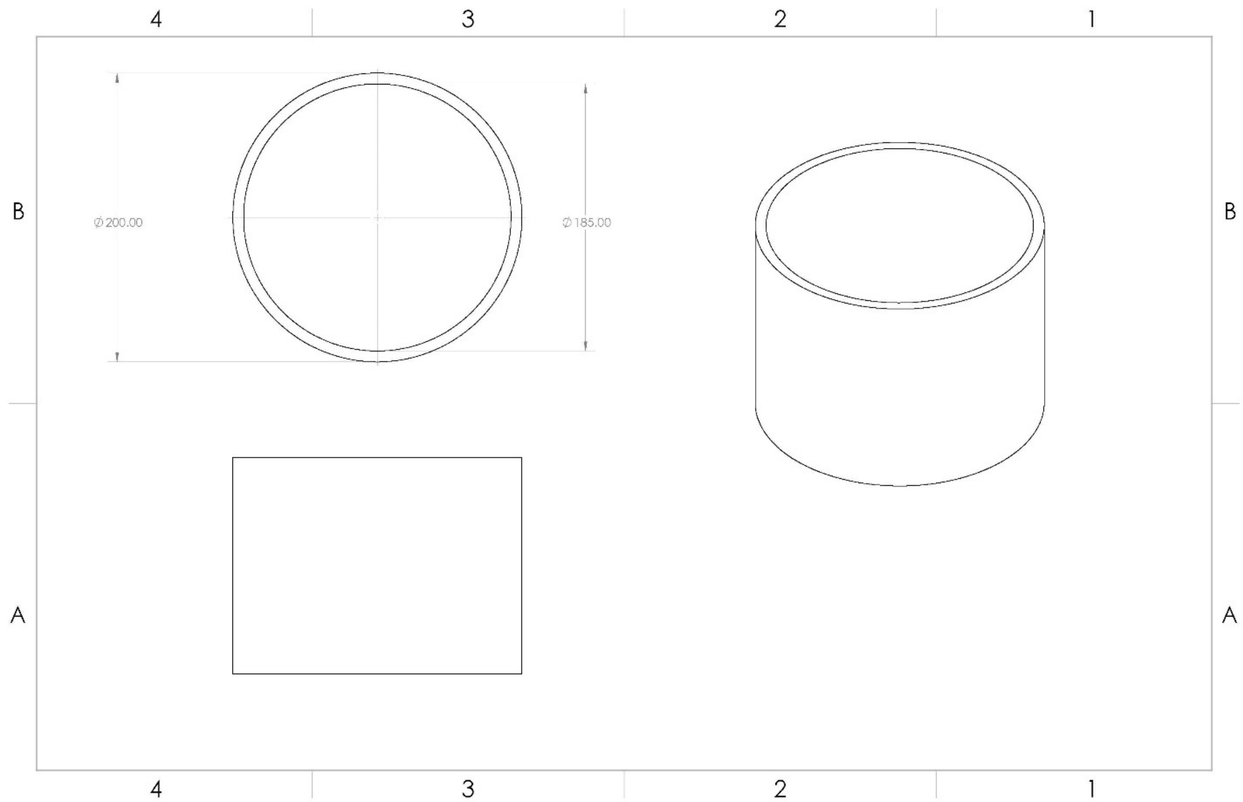

Figure 13: nozzle drawing

manhole flange

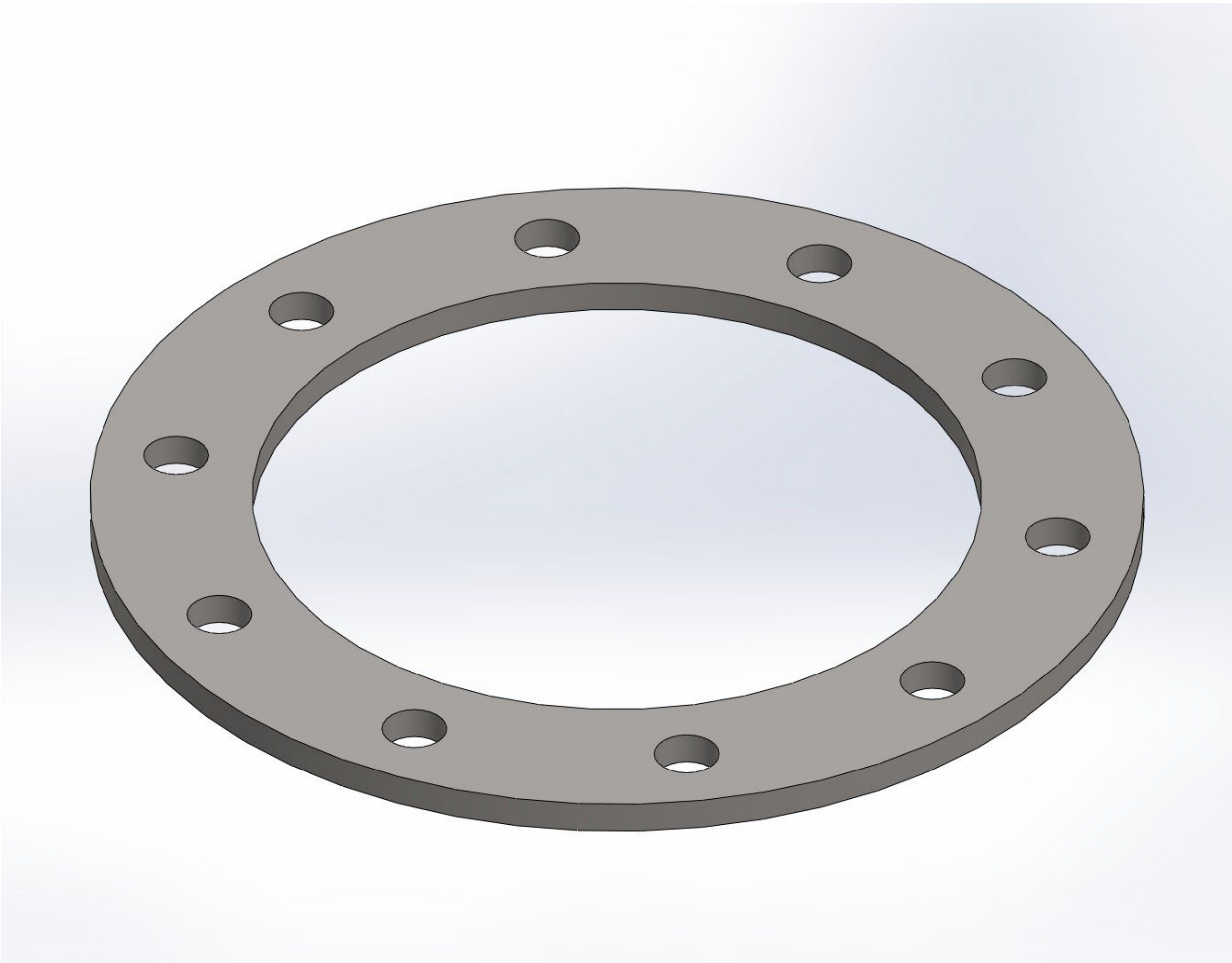

Figure 14: Manhole flange part solidworks design

Manhole flange cover

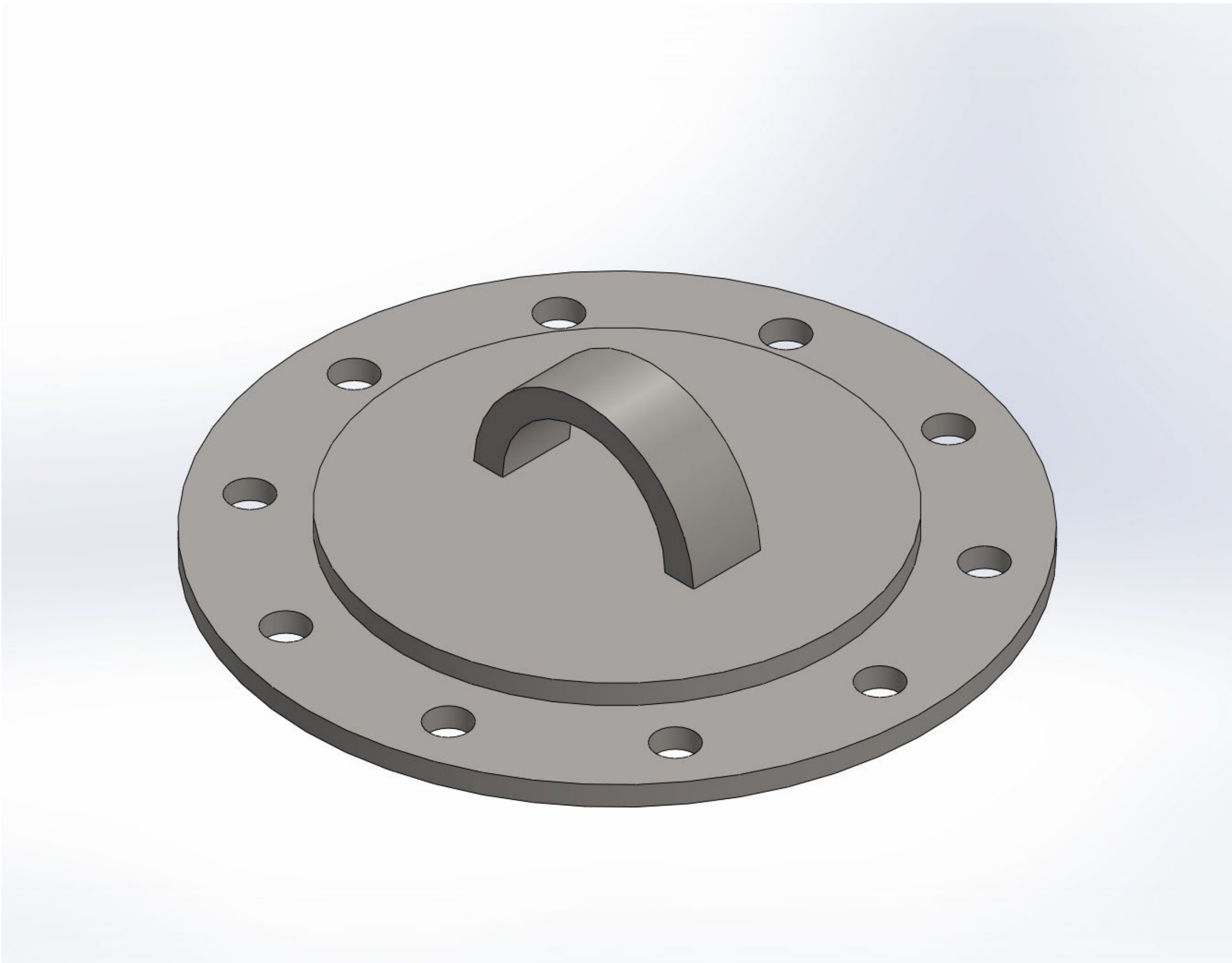

Figure 15: Manhole flange cover part solidworks design

Saddle

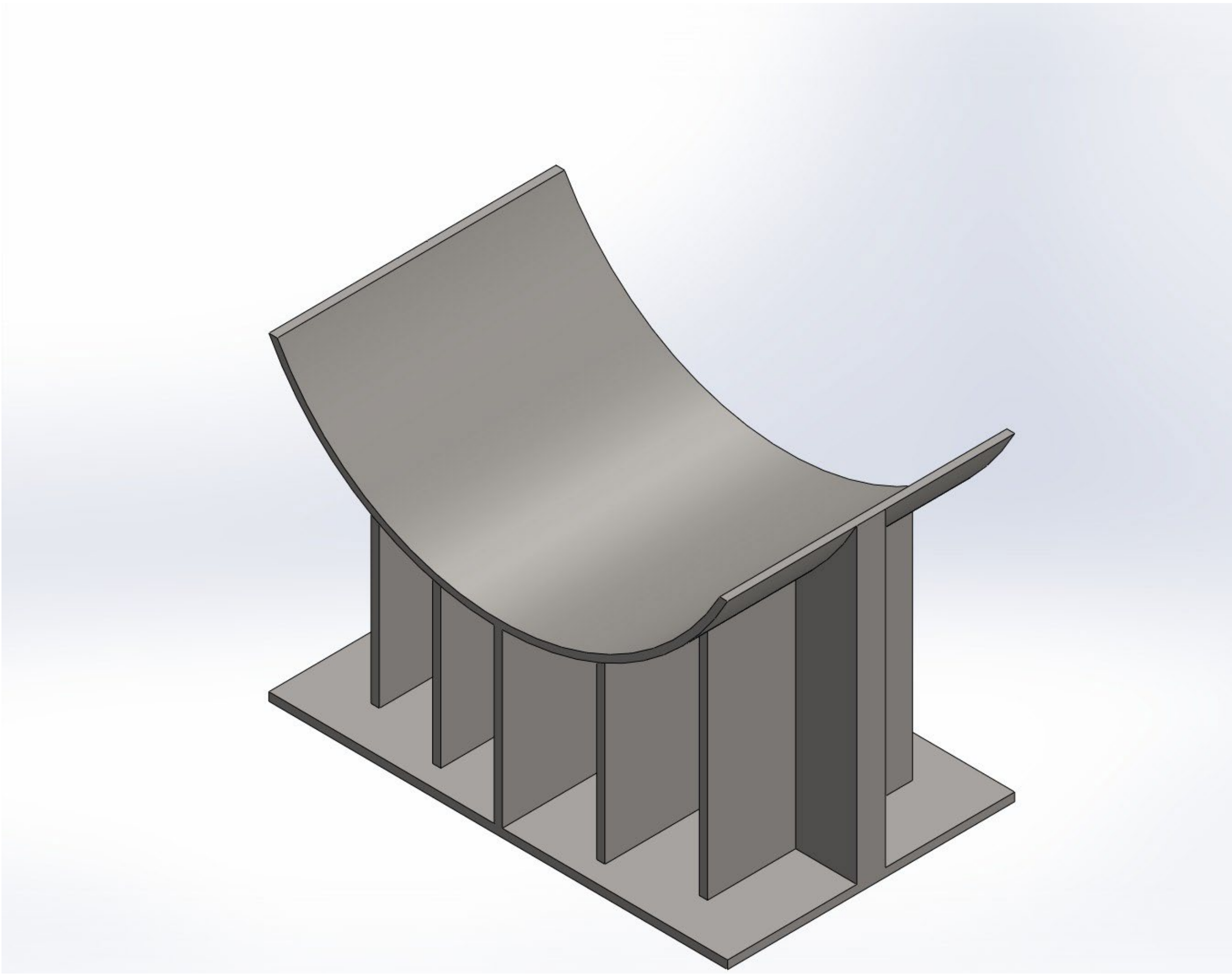

Figure 16: saddle part solidworks design

4.2. Assembly drawing of the Pressure vessel

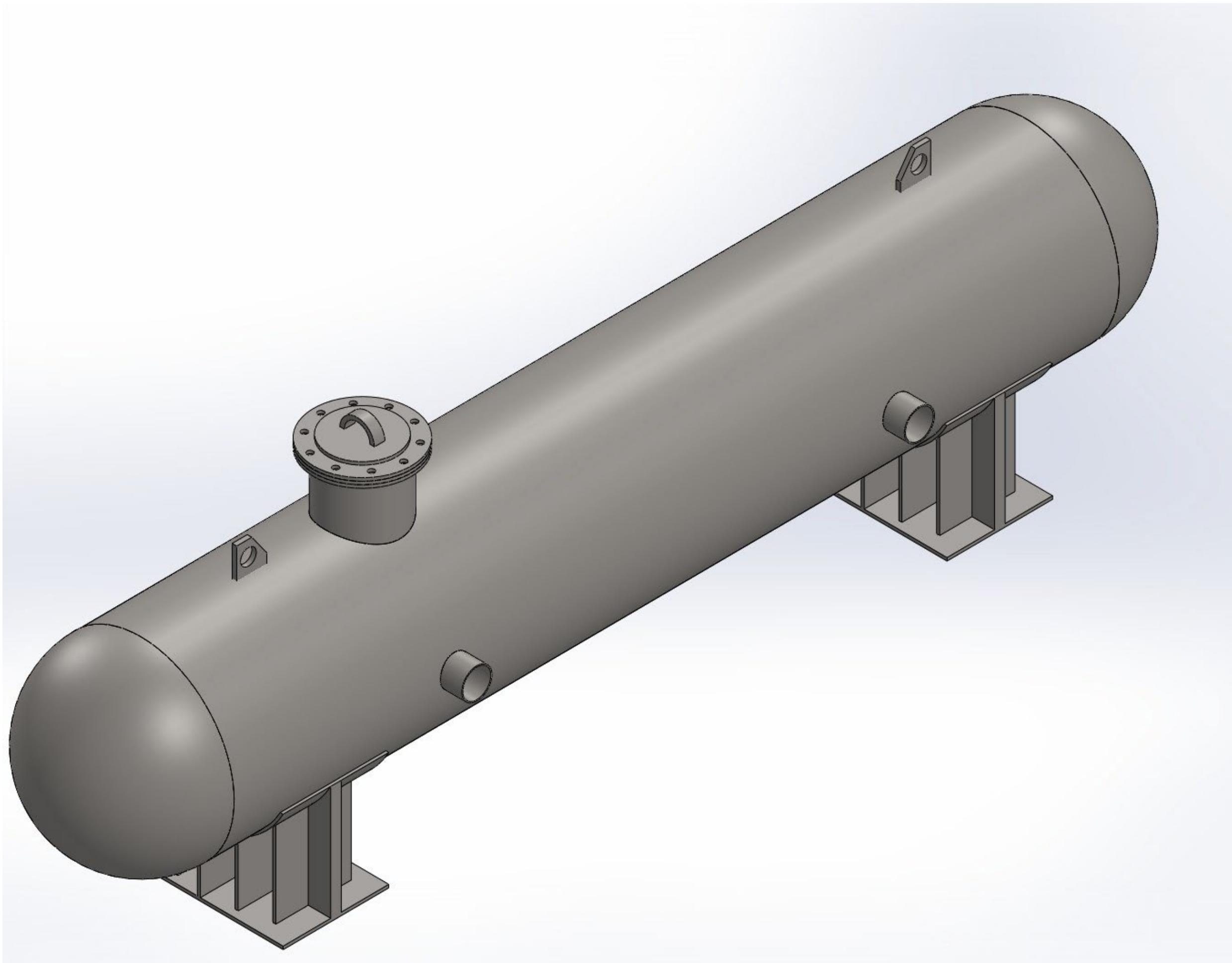

Figure 17: final assembly solidworks design

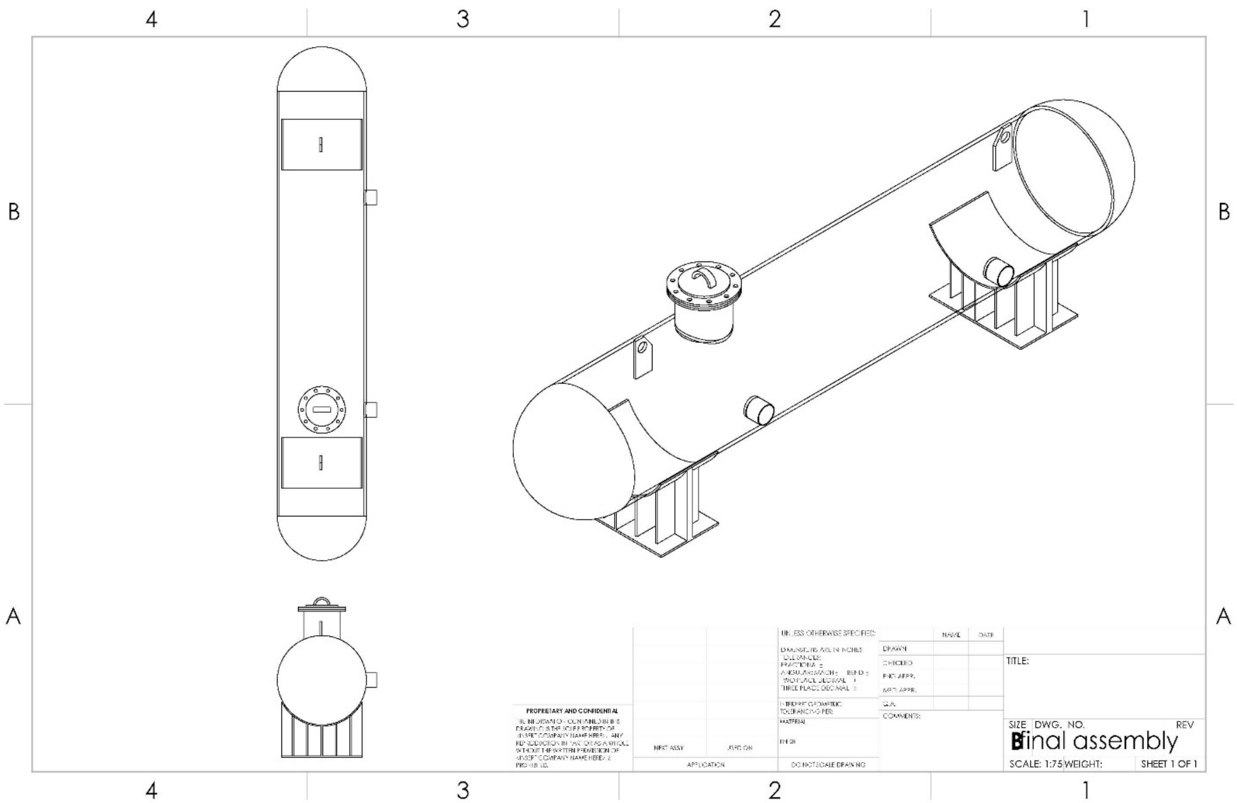

Figure 18: final assembly drawing

5. Chapter five Conclusions and Recommendations

In this report we have designed the components of the pressure vessel using ASME Section VIII division 1. The ASME is preferable as it has more Factor of safety compared to the IS.

It is very important to design each part of these vessels individually to obtain more accurate design.

The most stable stainless steels for the oxygen pressure vessel which has corrosive environment are the stainless steels with higher quantities of nickel, chromium with low carbon content which help in stabilization of the austenite structure and to avoid Inter Granular corrosion at the weldments. We can avoid corrosion of piping and vent lines by using low carbon stainless steels.

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