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Designing and Analysis of Cryogenic Storage Vessels

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Abstract—Cryogenics is a study of science which deals with the behavior of extreme low temperatures. Cold converts is a kind of a pressure vessel which is meant for storage of liquid oxygen and nitrogen or argon under required pressure conditions. The materials used for this equipment are discussed and analysed in this paper. The designing procedure follows according to the industry norms.

The procedure conforms to ASME SECTION 8, DIVISION-1 and DIVISION-2. The procedure for designing nitrogen cold convertor to the required specifications has been studied and modified to create a perfect storage cryogenic vessel. The design calculations and results have been shown.

Index Terms— Diameter, Liquid nitrogen, Maximumm shear stress, Storage capacity, Outer-shell, Inner-shell, Principal stresses, Thickness, Von misses Stress.Volumetric Strain.

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1 Introduction

THIS research paper gives the over view of designing and analysis of the cold converter storage vessel, in wich liquid oxygen and liquiud nitrogen or liquid argon are stored safely. The tank must sustain the working pressure otherwise the tank explodes and causes damage to itself and to its surrounding equipments.

Cryogenics refers to the entire phenomenon occurring below -150 or 123K. Cryogenics enginnering involves the design and development of systems and components which produce, maintain, or utilize low temperatures.

Cryogenics vessels are designed for storage and transport of liquid gases at sub-zero temperatures. Manufacturing of cryogenic tanks requires special technical and sophisticated fabrication techniques. Universal has developed thenecessary technology and has been manufacturing these crypgenic equipment like cryogenics vessels sice last 9 years.

1.2 Storage Vessel components

Different gauges and valves are required to monitor and stabilize the cryogenic vessel and these guages have a precise measauring capability, otherwise smallest change in the presure variations can leads to trouble. Hence different parameters of the vessel are contiounsly monitored.

The different gauages and valves which are used in the cryogenic vessel are vaporator, liquid container gauge, vaccum bursting disk, vent valve, pressure building valve,pressure building coil, pressure relief valve, Presure gauge, inner container bursting disk, liquid fill and withdrawl valve, economier regulator, vent valve..e.t.c
All thses gauges and valves have the capability to work even at the higher pressure environments without any malfunction.

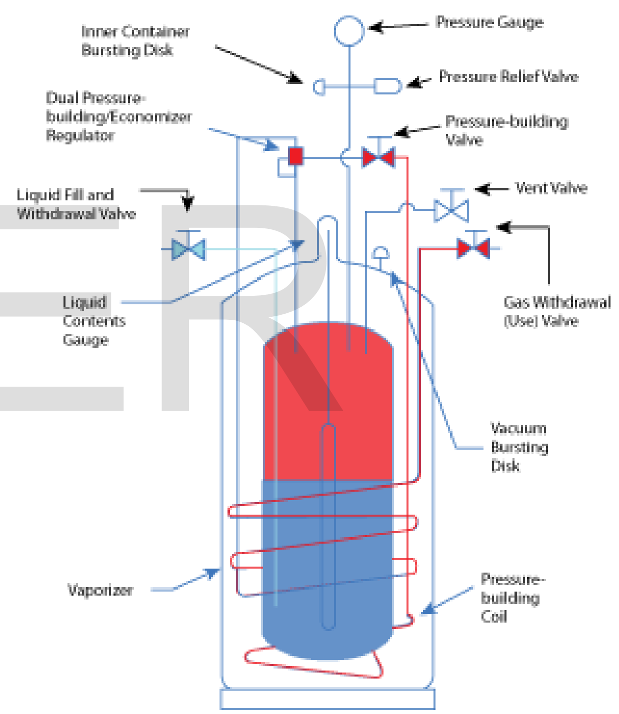

Fig 1.1 components of Storage vessel

All these components are carefully monitored and regulated by computers. These computer are pre-programmed to take necessary counter measures to avoid any accidents.The components and computers are powered by a local battery unit.
The important components in the cryogenic storage vessel are the pressure gauge and the pressure relief valve, because the pressure in storage vessel should always have to be maintained at a required presuure level and if it is not maintained then the storage vessel may leads to malfumction.
The various components of cold convertor are as follows:

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Shells

The shells of cold converter are of cylindrical sections. These are mainly two shells named as inner shells and outer shells. The inner shell is made up of stainless steel where as the outer shell is made up of carbon steel. The annular space between the shells is evacuated and is perlite insulation.

Dished ends

These form the end closer to cold converters. In the dished ends a sudden change in direction is avoided at the junction of cylindrical shell and formed end with a gradual change n shape reduces the local discontinuity stresses at the junction. The dished end may be hemi-spherical, tori-spherical or ellipsoidal.

Skirt

It provides support to the entire vessel. The skirt is usually welded directly to the vessel either to the bottom dished end or outside of the cylindrical shell. The bottom of the skirt of the cold converter must be securely anchored to the concrete foundation by means of anchor bolts embedded in the concrete to prevent overhauling from the bending moments induced by wind and seismic loads.

Nozzles

Nozzles are connections through which the vessel is connected to the piping instrumentation and other control equipment. These are welded to the shell. Nozzles can be from seamless pipes, forged hallow bars. These are connected by means of flanges, screw type connections or directly welded.

Pressurization coil

The unit consists of aluminum star fins by the side of tank and is gravity fed by valve and the desired pressure can be obtained. Its output is controlled by the regulator (pressure control valve).

Control cabinet

The valves gauges and fittings required for the operating the convertor are located in light alloy shelter mounted on the outer shell. For example: vacuum gauge, rupture disc, inlet and outlet valves etc.

1.3 Structure of Cryogenic Storage vessel

The cryogenic storage vessel is designed in such a way that it has two different shells, first one is called the innershell or product container and the other is called as outershell and it is also know as vaccum jacket. The air between the gaps are sucked out with the help of air separation unit and it is made vaccumed for better insulation. In some cases different types of powders and gasses are used for insulation and the type of insulation is always independent on the type of storage and environmental conditions.

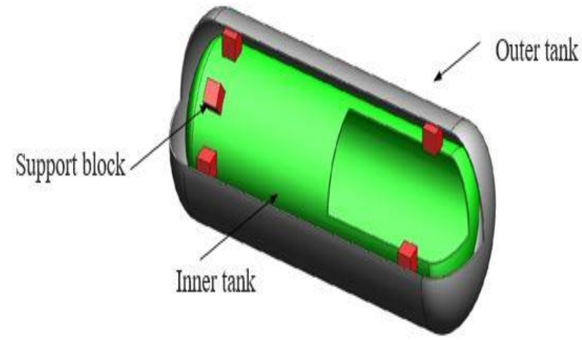

Fig 1.2 Structure of Storage vessel

Multilayer insulation, powder insulators and fabric materials are used as insulators in larage capacity crypgenic containers.

An insulation materials used to insulate the cryogenic fluids from the vapour or air and the other gases which are present in the atmosphere. The effectiveness of the storage vessel depend on the insulation hence it is very important parameter that should be considered in the design of the cryogenic storage vessels.

And these two shells (tanks) are connected by a support blocks, these support blocks will acts as a stiffners and it helps in maintaining structural stability of the vessel it absorbs the stresses and it keep the product shell securely.

To minimize heat transfer and sustain very low temperatures, the storage vessel must be specially designed. Storage vessels for liquid oxygen, liquid nitrogen and liquid argon are commercially available in various capacities. The storage vessels may be vertical, spherical, or horizontal depending on the site and consumption requirements

1.3.2 Air separation unit.

The air is sucked from atmosphere. The sucked air is compressed in a five stage compressor with an inter cooler. The compressed air consists of oil, moisture and carbon dioxide. These impurities are obstructions for the liqueficaction because carbon dioxide and moisture forms ice at lower temperatures, which is obstruction for the flowing fluids. So these impurities are to be removed.

The compressed air is passed through a filter, which separate oil from the compressed air. The oil free compressed air is now passed through a refrigerating unit, which cools the compressed air. These droplets are collecting in a separate vessel. Now the air is passed through a vessel consisting of molecular sieves, which absorbs carbon dioxide present in the compressed air.

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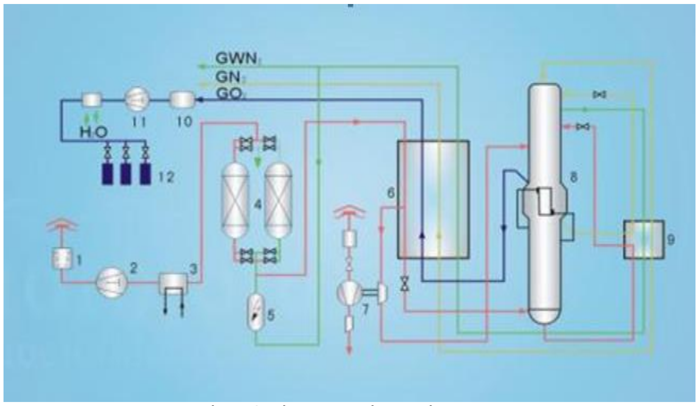

Fig 1.3 Air separation unit

Now this air is passed through post filter, which removes further impurities. The filtered air is passed through post filter, which removes any further impurities. The filtered air is sent through the cold box. This cold box is mainly consists of the following

1) Heat exchangers
2) Exchange turbines
3) Inlet and outlet manifolds
4) A column consisting of aluminium trays.

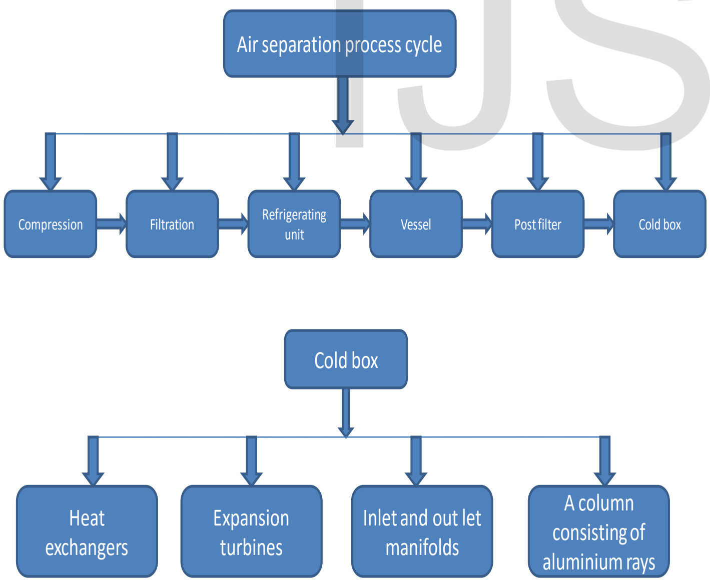

Fig 1.4 Flow chart of Air separation unit

The compressed air is passed through heat exchanger, which reduces the temperatures of the air around -140˚C. The cooling of air is allowed by passing the cold non condensable gases and gaseous nitrogen. The cold air is passed through the expansion turbine in which the compressed air is expanded. Due this expansion the temperature is reduced to around -180˚C. At this low temperature the air is liquefied. The liquid air is then passed through a column consisting of aluminium trays from top to bottom. During this flow the evaporation of nitrogen and other gases takes place and only oxygen is collected in bottom reservoirs. The liquid nitrogen is produced at the top of the column. Due to this gaseous nitrogen can be liquefied by giving the heat energy to the liquid oxygen. Here the liquid oxygen is evaporated. This liquid nitrogen is formed at the column and Pumped to the cold convertor.

The condensable gaseous nitrogen is passed through the heat exchanger, which cools the incoming compressed air, thus liquid nitrogen and oxygen produced and collected in cold convertor.

Argon which has 0.93% content of air which has a boiling point in between oxygen and nitrogen presented as impurity in the both liquid nitrogen and liquid oxygen. In order to get pure liquid nitrogen n argon percentage should be reduced. This can be down by using the other column, which separates argon.

2. Designing of Cryogenic Vessel

Different variables like the thickness of the product vessel, diameter of product vessel, thickness of the outershell, diameter of the outershell and the thickness of the stiffners are calculated. Those calculations are depended on the type of design codes.

2.2 Design codes

A design code is a document that sets rules for the design of a new development. It is a tool that can be used in the design and planning process. The design and manufacture of pressure vessels are done according to some regulations and codes. They assure safety in operations, quality control and assurance. The codes that are adopted by pressure vessels manufactures are

1) ASME selection VIII division- I & II (American codes)

2) PD 5500 (British code)

3) AD Merkblatter (German code) and

4) IS 2825 (Indian code)

The basic aims of the codes are same, but their approach is different. Their use of raw materials, historical back ground, design and manufacture are different for different codes in different countries.

The features and limitations of codes are given below

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1) ASME selection VIII division- 1

This code provides the formulas to compute thickness and stresses of the vessel. They provide procedures to design the vessel. According to this code the wall thickness is computed by some assumptions. They should not exceed maximum allowable stresses, stresses should be uniformly distributed and there should be higher factor of safety. The limitations are

1) Pressure should not exceed 3000 Psi.

2) Vessels having internal or external operation pressure not exceeding 15Psi with no limit on size.

3) Nominal water containing capacity of 120 gallons or less.

4) Vessels having an inside diameter not exceeding 6" with no limitation on pressure.

2) ASME selection VIII division-2

In this code lower safety is considered as a result higher allowable stresses are permitted in designing the vessel. It also ensures safety, design, fabrication and quality control. This code is applicable only when the vessel is fixed and it has no pressure limits.

3) PD 5500

This code specifies requirements for design, construction, inspection and testing of welded pressure vessels. This code does not include vessels that are subjected to directly generated heat of flame impingement from a firing process. The limitations are pressure inside the vessel should not exceed 140m bar above atmospheric pressure and 6m bar below atmospheric pressure. It is not applicable for low pressure and single vertical axis of revolution, multi layer vessels, and transport pressure vessel.

4) AD Merkblatter

Seven-trade association of Germany, which together forms the AD codes, compiles the AD Merkblatter. This code covers safety requirements, which must be adopted for normal condition of operation. The necessary requirements are satisfactory design, manufacture and operation of the pressure vessel. To a large extent AD Merkblatter code is based on DIN standards (German standards). AD Merkblatter consists of the following series.

Series A	Equipment
Series B	Design
Series C	Fundamentals
Series H	Manufacture
Series HP	Manufacturing and testing
Series N	Non metallic materials
Series S	Special cases
Series W	metallic materials

5) IS 2825

This code covers minimum construction requirements for the design, fabrication, inspection, testing and certification of welded unfired pressure vessels in ferrous as well as in non-ferrous materials. This code does not include

1) Vessel designed for pressure exceeding 200kgf/cm²

2) When the ratio of outside to inside diameter of the shell exceeds 1.5

3) Hot water supply storage tanks heated by steam or any other indirect means.

4) Vessels having an internal operating pressure not exceeding 1 kgf/cm² with nomination size.

5) Vessel having an internal diameter not exceeding 150 mm with no limitation on size

2.3 Design calculations.

Different calculations of several variabels are shown below

2.3.2 Capacity calculations

Net capacity Q_1 = 65 m^3
Vapour space provided in tank = 5% of capacity
Gross capacity of cold converter Q = net capacity + vapour space
= 68.25 m^3
Inner diameter of inner cylinder D_i = 2698 mm
Radius of inner dished end r_i =1350 mm
Volume of two dished ends V_d = $4/3\ \pi r_i^3$
= 10.277 m^3 – both
= 5.138 m^3 – each dished ends Volume of cylindrical shell
= $LD^2\pi/4$
Volume of cylindrical shell = gross capacity – volume of dished ends
= 57.98 m^3
From the above two equations

$LD^2\pi/4$ = 57.98 m^3
Length of cylindrical shell L (TL to TL) = 10.14 m
Height of the shell ($HD^2\pi/4$) =59.85 m^3
H = 10.473 m

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Height of the liquid shell = height of shell – one dished end
= 10.473 + 1.350
= 11.823 m^3

Pressure due to static head= height of liquid × density of fluid/10
= 0.957 kg/cm^2

Hence design pressure = working pressure × 1.1 + atmospheric pressure + pressure due to static head
= 18.5×1.1 + 1.0332 +0.957
= 22.3402 kg/cm^2

2.3.3 Design of inner shell

Design of inner cylindrical shell (under internal pressure)
Thickness of shell (as per ASME SEC VIII DIV 1)

$$T = PR_i / (SE - 0.6P) + C.A + T.A$$

Where P = design pressure = 22.3402 kg/cm^2
S = allowable stress = 1406.14 kg/cm^2
R_i = radius of inner shell = 1350 mm
E = joint efficiency = 1
C.A = corrosion allowance = 0
T.A = thinning allowance = 0

Hence thickness T = 20.13 mm ≈ 20.2 mm
Adopted thickness = 20.2 mm

2.3.4 Design of inner dished ends

Dished ends are of spherical type
Thickness of dished end is

$$T = PR_i / (2SE - 0.2P) + C.A + T.A$$

Where
P = design pressure = 22.3402 kg/cm^2
R_i = 1350.33 mm
S = 1406.14 kg/cm^2
C.A = 0
T.A = 1

Hence thickness of inner dished end T_d = 11.74 mm
≈ 12 mm
Adopted thickness T_d = 12 mm

2.3.5 Inner cylindrical shell design (under external pressure)

External diameter D_o = 2698+ (2×20.2)
= 2738.4 mm
Thickness of inner shell t =20 .2mm
Length of inner cylindrical shell = 10140.23 mm
Effective length L = 10140.23 + 2(r_d/3)
Where
r_d = radius = 1350 mm
L = 11040.23 mm

D_o/t = 135.564

From ASME SEC VIII DIV 1

From graph factor A = 0.00008
Since the graph (HA- 1) is falls on left side

Pressure P_a = 2AE / 3(D_o/t)
P_a = 5.34 psi

External pressure P=atmospheric pressure = 15 psi
Since P_a < P the design is not safe, so we use stiffener rings

2.3.6 Design of outer cylindrical shell design (under external pressure)

We are using carbon steel SA 516 TP 70.
Inner diameter of outer cylindrical shell = 3050 mm
Thickness of outer cylindrical shell = 20.2 mm
Outer diameter of outer cylindrical shell D_o= 3074 mm
Corrosion allowance C.A = 3.0
Effective length L =1240.23 mm
L/D_O = 3.65
D_O/t = 152.1782

From ASME SEC VIII DIV 1
From graph factor A = 0.00009
As the graph is falls down on left side we cannot obtain factor 'B' value
Pressure P_a = 2AE / 3(D_o/t)
P_a = 9.448 psi
External pressure P= 15 psi
Since P_a < P the adopter dimensions are not adequate to with stand the external pressure. For that purpose we have to provide stiffener rings on external cylindrical shell.

2.3.7 Stiffener ring calculations under external pressure
Inner shell

We provide 2 stiffener rings, so there are 3 equal spaces.
Outside diameter of cylindrical shell D_o = 2722 mm
Provided thickness t = 20.2 mm
Corrosion allowance C.A = 0
Length between stiffener rings L_s =3680.076mm
(Assuming 2 stiffener rings)
L/D_o = 1.35
D_o/t = 137

From ASME SEC VIII DIV 1

From graph factor A = 0.00023
From graph factor B = 3000

Pressure P_a = 4B / 3(D_o/t)

P_a = 29.684 psi
External pressure P = 15 psi
Since P_a > P the adopted dimensions are not adequate to with stand the external pressure. So, our design is safe.

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Outer shell

Outside diameter of cylindrical shell D_o =3074 mm
Provided thickness t = 20.2 mm
Corrosion allowance C.A = 3 mm
Length between stiffener rings L_s = 3740 mm
L/D_o = 1.218
D_o/t = 152.17
From ASME SEC VIII DIV 1
From graph factor A = 0.00025
From graph factor B = 3400

Pressure P_a = $4B / 3(D_o/t)$

P_a = 29.79 psi
External pressure P = 15 psi

Since $P_a > P$ the adopted dimensions are not adequate to with stand the external pressure. So, our design is safe.Under this geometry conditions the vessel is designed. Some dimensions are calculated while some others are assumed and some others are taken from design standard codes and graphs

3 Cryogenic Materials

Austenitic steels, stainless steels, fine grain double normalized and tempered nickel steels, copper and aluminum are excellent materials, which can be withstand cryogenic temperature.

Stainless steels

Austenitic stainless steels are suited for cryogenic applications as they remain tough and ductile even at -269°C.

9% Nickel steels

9% nickel steels are usually classified as ferrite steel however this constitutes austenitic ferrite and magnetite. The presence of austenitic has given excellent strength and resistance to brittle fracture.

The decrease in ductility with decrease in temperature below zero is very gradual and as chirpy v notch values are above 25 Ft lbs (346 or 4.4 kg/cm²) at -200°C. In case of fabrication proven safety and favorable cost has made it widely used material ins cryogenic equipment for storing and transporting liquefied gases such as Nitrogen, Methane and Ethylene.

Extensive tests to destructions are carried out on tanks filled with liquid nitrogen have demonstrated that quenching and tempering and that post weld treatment was not beneficial. ASME code specified that it is not necessary to post weld, heat treatment up to and including 2 inches thickness (up to about 50mm).

Aluminium alloys

Aluminium alloys like 5083 (Mg 0.445%, Mn 0.6% and cr 0.15%), 6003 (Mn 1.26% and Cu 0.12%) are used in manufacture of cryogenic storage vessel, columns in air separation plant and brazed aluminium of heat exchangers. These show no ductile to brittle transformation even down to the temperature of liquid helium i.e., -269°C.

The toughness properties of aluminium are so well known that it was not considered necessary to specify the minimum value in ASME or ASTM codes. Notched yield ratio, tear resistance, critical stress intensity is high. Fatigue strength also increases with decrease in temperature.

Copper alloys

Copper alloys like alpha brass and phosphorous-di-oxide, copper were easy material of construction for cryogenic equipments. Even today copper tubes are used for trays in small air separation plants. Copper has low yield strength in annealed condition. Copper alloys have lesser yield strength when compared to steel and are unaffected by temperature changes.

Alluminum and Nickel steels are better suitable for production of the cryogenic storage vessel hence in order to select one stress analysis should be done on both materials and the based on the stress analysis results we can select a material which is best suited for the cryogenic tank production. And that material is later discussed in conclusion

4 Design analysis of cryogenic vessel.

The first simualation is done on the cryogenic vessel which is made up of with the aluminium 5083. And its simulation results are shown below

4.2 Simulation: 1

Analyzed File:	Cryogenic vessel
Autodesk Inventor Version:	2015 (Build 190159000, 159)
Creation Date:	15-May-16, 10:50 PM
Simulation Author:	Pasala Venkata Satish

Project Info (iProperties)

Author	Pasala Venkata Satish
Part Number	2ndcc
Designer	Pasala Venkata Satish
Date Created	07-May-16

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Physical

Material	Aluminum 5083 87 Cold Formed
Density	0.0960986 lbmass/in^3
Mass	31879.8 lbmass
Area	4762870 cm^2
Volume	5436260 cm^3
Center of Gravity	x=-0.0000000000029165 cm y=-525.627 cm z=-154.6 cm

Note: Physical values could be different from Physical values used by FEA reported below.

General objective and settings:

Design Objective	Single Point
Simulation Type	Static Analysis
Last Modification Date	15-May-16, 10:45 PM
Detect and Eliminate Rigid Body Modes	No

Mesh settings:

Avg. Element Size (fraction of model diameter)	0.1
Min. Element Size (fraction of avg. size)	0.2
Grading Factor	1.5
Max. Turn Angle	60 deg
Create Curved Mesh Elements	Yes

Material(s)

Name	Aluminum 5083 87 Cold Formed	
General	Mass Density	0.0960986 lbmass/in^3
	Yield Strength	41335.8 psi
	Ultimate Tensile Strength	55839.5 psi
Stress	Young's Modulus	10007.6 ksi
	Poisson's Ratio	0.33 ul
	Shear Modulus	3762.26 ksi
Part Name(s)	Cryogenic Vessel	

Operating conditions

Load Type	Pressure
Magnitude	250.000 psi

Selected Faces

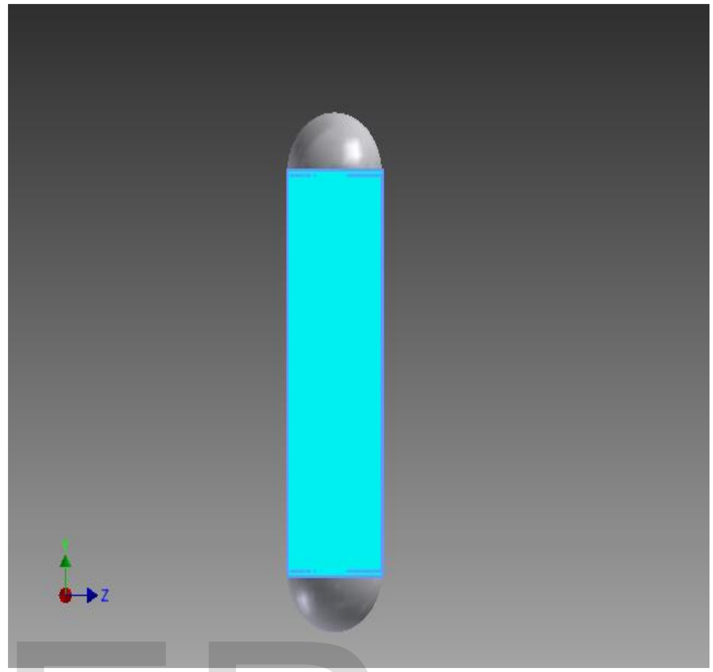

Fig 4.2.1 Selecting face for pressure

The applied pressure in the vessel is 250 psi according to the ASME standards and the external pressure is taken as 150 psi.

The Figure 4.2.2 indiactes the diferent constrains that are located at the different location of the Storage vessel. The constrains are displayed in blue in color.

Constraint Type	Fixed Constraint

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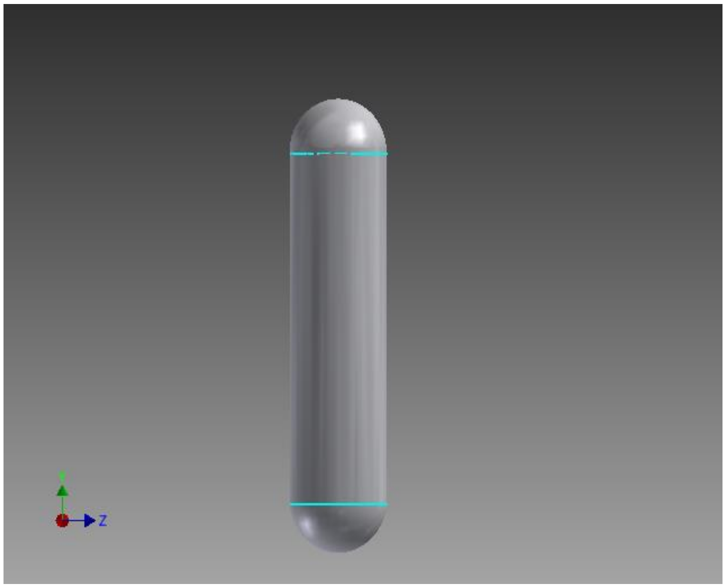

Fig 4.2.2 constrained position in vessel for analysis

Result Summary

Name	**Minimum**	**Maximum**
Volume	5.43626E+009 mm^3	
Mass	31879.8 lbmass	
Von Mises Stress	0.000866688 MPa	117.146 MPa
1st Principal Stress	-23.4491 MPa	89.0687 MPa
3rd Principal Stress	-125.807 MPa	53.9125 MPa
Displacement	0 mm	2.4775 mm
Safety Factor	2.43287 ul	15 ul
Stress XX	-125.806 MPa	77.8312 MPa
Stress XY	-39.6739 MPa	36.9261 MPa
Stress XZ	-64.459 MPa	61.6759 MPa
Stress YY	-79.1859 MPa	58.5517 MPa
Stress YZ	-36.8943 MPa	30.912 MPa
Stress ZZ	-124.757 MPa	78.149 MPa
X Displacement	-2.2528 mm	2.20901 mm
Y Displacement	-1.06415 mm	1.02019 mm
Z Displacement	-2.26653 mm	2.32907 mm
Equivalent Strain	0.0000000141568 ul	0.00152525 ul
1st Principal Strain	-0.000021337 ul	0.000974366 ul
3rd Principal Strain	-0.00168837 ul	0.0000616597 ul
Strain XX	-0.00164065 ul	0.000974262 ul
Strain XY	-0.000764729 ul	0.000711764 ul
Strain XZ	-0.00124247 ul	0.00118883 ul
Strain YY	-0.00124163 ul	0.000576865 ul
Strain YZ	-0.000711151 ul	0.00059584 ul
Strain ZZ	-0.0016662 ul	0.000855221 ul
ContactPressure	0 MPa	8.51499 MPa
ContactPressure X	-1.67133 MPa	1.55096 MPa
ContactPressure Y	-0.00151738 MPa	8.16541 MPa
ContactPressure Z	-2.41261 MPa	1.7797 MPa

Von Mises Stress

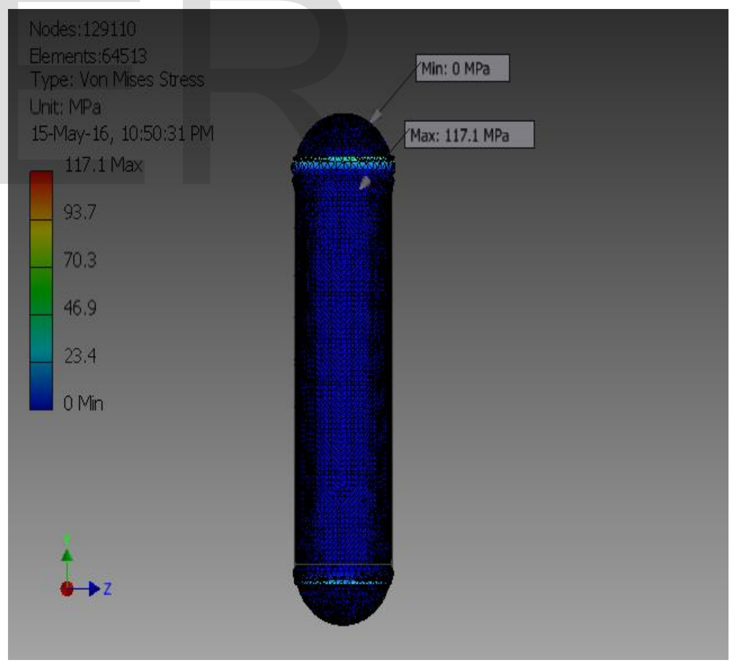

Fig 4.2.3 application of von mises stress

The maximum stress produced in the vessel is 117.1 mpa and its location is near to the welded region of the vessel.

In analysis 1st principal stresses and 3rd principal stresses are important hence those two analysis reports are also shown below. The different colors indicates the different stresses acting at the different locations of the vessel

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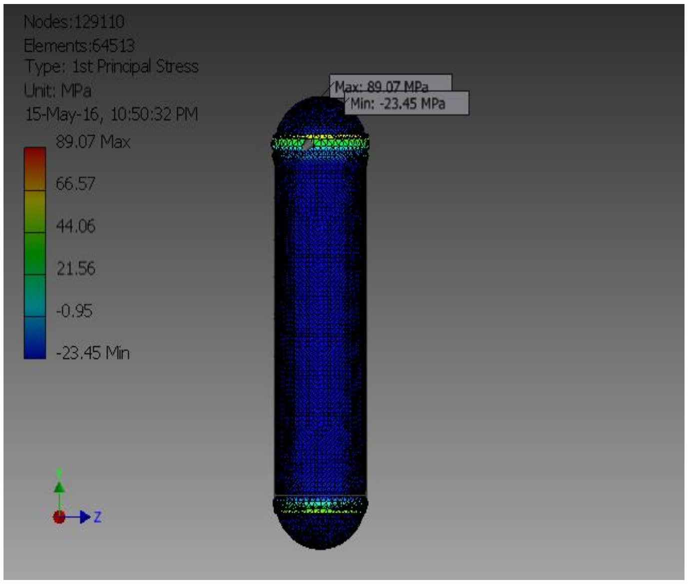

Fig 4.2.4 principal stress acting on vessel

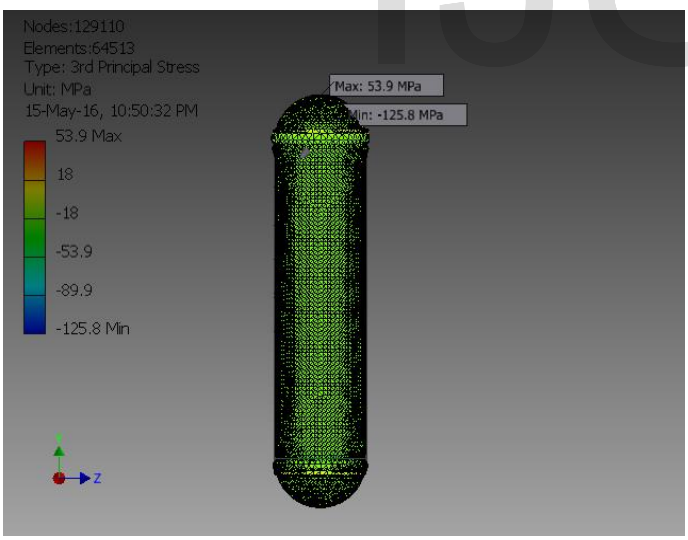

Fig 4.2.5 3rd principal stress acting on vessel

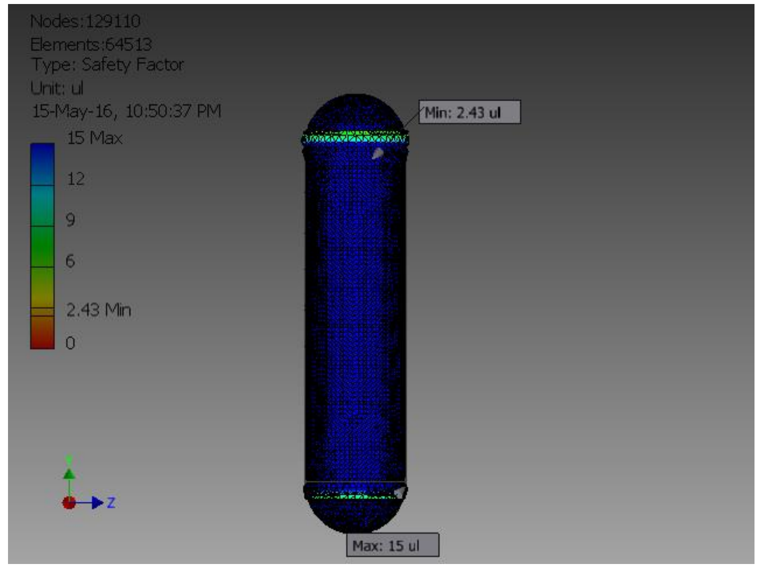

Fig 4.2.6 Safety Factor

4.3 Simulation: 2

The second simulaation is done on the cryogenic vessel which is made up of with the Nickel-Copper Alloy 400. And its simulation results are shown below

Analyzed File:	Cryogenic Vessel
Autodesk Inventor Version:	2015 (Build 190159000, 159)
Creation Date:	15-May-16, 10:54 PM
Simulation Author:	Pasala Venkata Satish

Project Info (iProperties)

Author	Pasala Venkata Satish

Part Number	2ndcc
Designer	Pasala Venkata Satish
Date Created	07-May-16

_Physical

Material	Nickel-Copper Alloy 400
Density	0.319004 lbmass/in^3
Mass	105827 lbmass
Area	4762870 cm^2

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Volume	5436260 cm^3
Center of Gravity	x=-0.0000000000029165 cm y=-525.627 cm z=-154.6 cm

Note: Physical values could be different from Physical values used by FEA reported below.

General objective and settings:

Design Objective	Single Point
Simulation Type	Static Analysis
Last Modification Date	15-May-16, 10:53 PM
Detect and Eliminate Rigid Body Modes	No

Mesh settings:

Avg. Element Size (fraction of model diameter)	0.1
Min. Element Size (fraction of avg. size)	0.2
Grading Factor	1.5
Max. Turn Angle	60 deg
Create Curved Mesh Elements	Yes

Material(s):

Name	Nickel-Copper Alloy 400	
General	Mass Density	0.319004 lbmass/in^3
	Yield Strength	31908.3 psi
	Ultimate Tensile Strength	80931.1 psi
Stress	Young's Modulus	26005.3 ksi
	Poisson's Ratio	0.315 ul
	Shear Modulus	9887.93 ksi
Part Name(s)	Cryogenic vessel	

Operating conditions:

Load Type	Pressure
Magnitude	250.000 psi

The body contacts along with selected faces are same for the both simulations hence pictures of selected phases are skipped. The applied pressure in the vessel is 250 psi according to the ASME standards and the external pressure is taken as 150 psi.

Result Summary

Name	Minimum	Maximum
Volume	5.43626E+009 mm^3	
Mass	105827 lbmass	
Von Mises Stress	0.00162306 MPa	117.319 MPa
1st Principal Stress	-21.2942 MPa	84.0095 MPa
3rd Principal Stress	-125.093 MPa	50.3036 MPa
Displacement	0 mm	0.953784 mm
Safety Factor	1.87523 ul	15 ul
Stress XX	-125.092 MPa	73.8974 MPa
Stress XY	-38.9344 MPa	36.2063 MPa
Stress XZ	-64.2913 MPa	61.4116 MPa
Stress YY	-76.3419 MPa	54.3181 MPa
Stress YZ	-36.5436 MPa	30.2902 MPa
Stress ZZ	-123.735 MPa	74.8874 MPa
X Displacement	-0.868379 mm	0.853062 mm
Y Displacement	-0.40084 mm	0.384769 mm
Z Displacement	-0.875101 mm	0.898574 mm
Equivalent Strain	0.00000000941988 ul	0.000583016 ul
1st Principal Strain	-0.00001081 ul	0.000365483 ul
3rd Principal Strain	-0.000651899 ul	0.0000239238 ul
Strain XX	-0.000634373 ul	0.000365446 ul
Strain XY	-0.000285548 ul	0.00026554 ul
Strain XZ	-0.000471517 ul	0.000450397 ul
Strain YY	-0.00046364 ul	0.000221503 ul
Strain YZ	-0.000268013 ul	0.00022215 ul
Strain ZZ	-0.000643419 ul	0.000322807 ul
Contact Pressure	0 MPa	7.99854 MPa
Contact Pressure X	-1.61752 MPa	1.50136 MPa
Contact Pressure Y	-0.00151559 MPa	7.64802 MPa
Contact Pressure Z	-2.33956 MPa	1.72514 MPa

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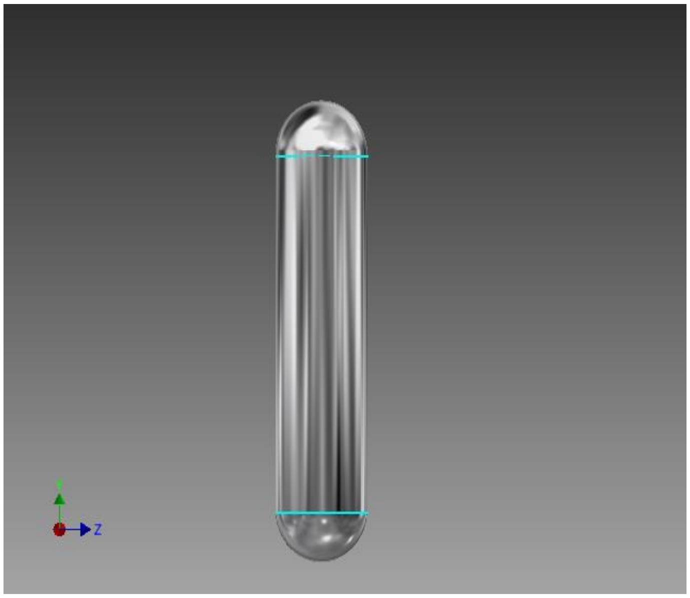

Fig 4.3.1 constrained position in vessel for analysis

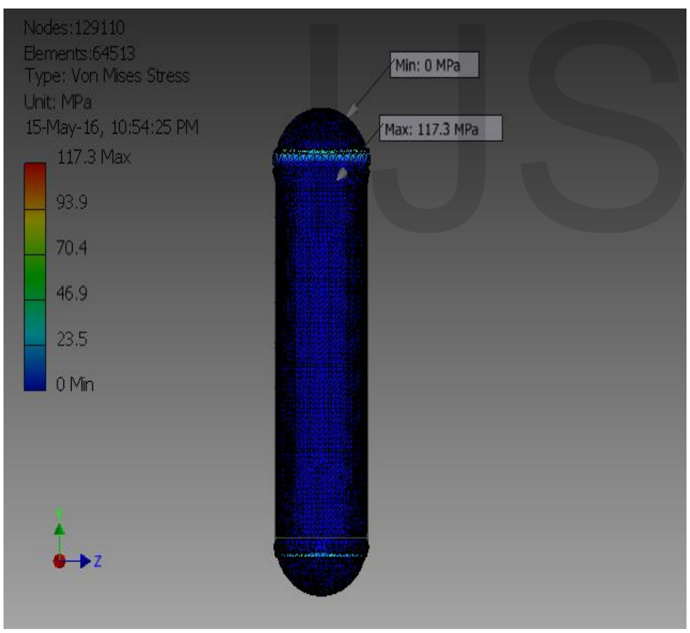

Fig 4.3.2 application of von mises stress

In Fig 4.3.1 and 4.3.2 shows the coffnstraints locations and the von mises stress are showed at the differentlocation of the cryogenic storage vessel. The maximum stress applied on the vessel is shown in the simulation and it is 117.3 Mpa.

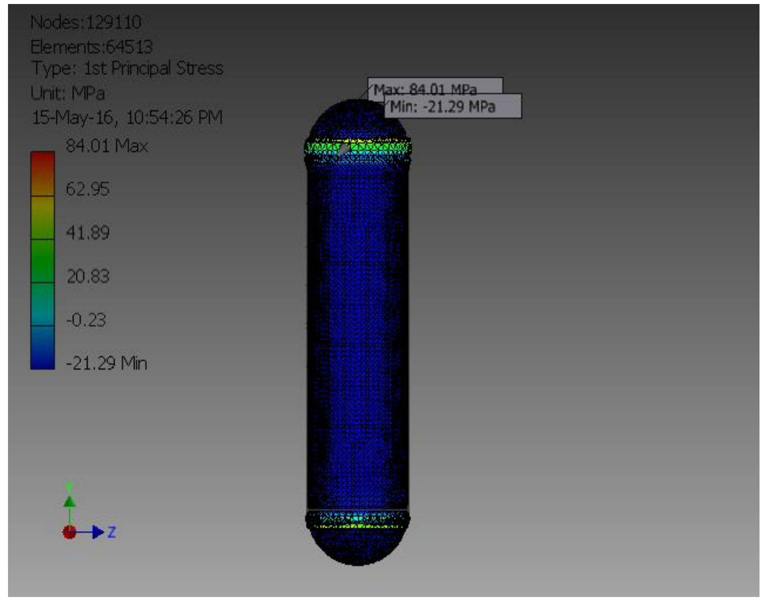

Fig 4.3.3 1 st principal stress acting on vessel

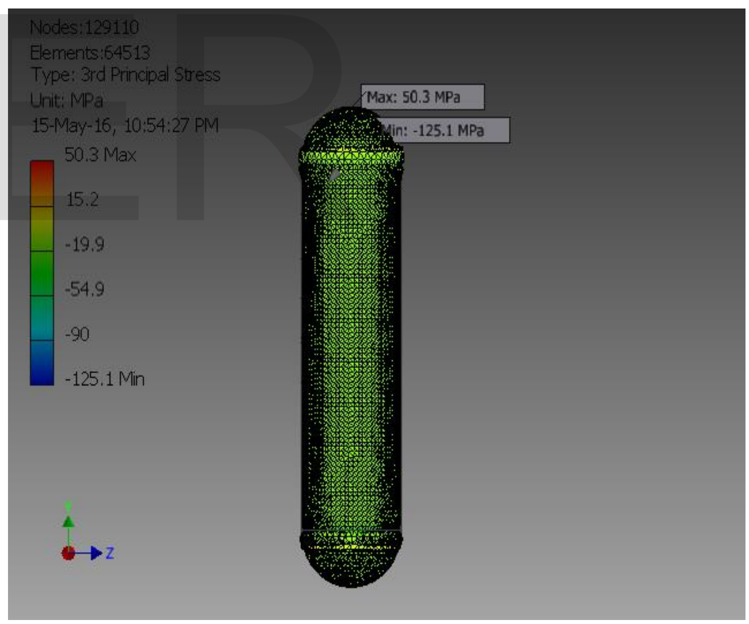

Fig 4.3.4 3rd principal stress acting on vessel

The fig 4.3.3 and 4.3.4 shows the 1 st principal stress and the 3 rd principal stresses which are produced in the vessel with the application of pressure. The maximum stress values produced in 1 st principal stress is 84.01Mpa and the maximum stress produced in the 3 rd principal stress is 50.3 Mpa

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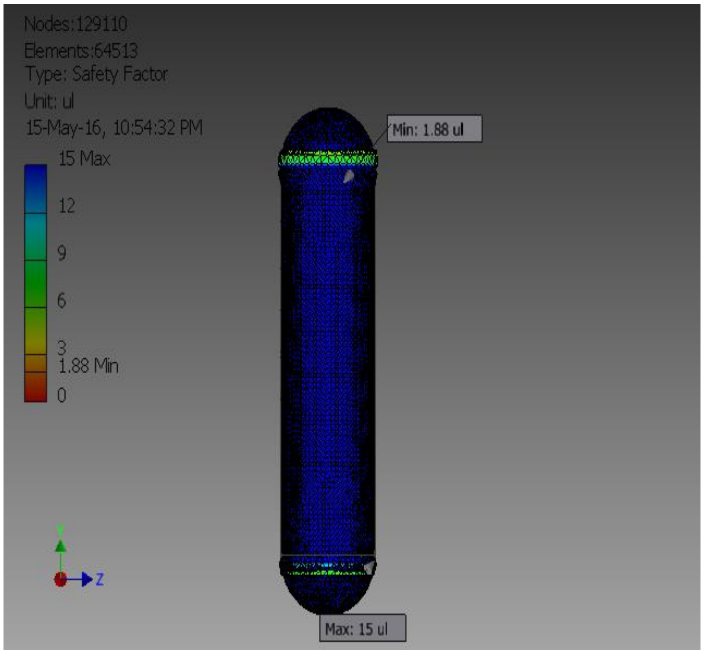

Fig 4.3.5 Safety Factor

The figure 4.3.5 shows the information regarding the safety factor of the vessel which is made up of nickel copper steel.

5 Conclusion

Hence from the obtained stress analysis reports it is clear that Nickel copper is better suited of producing cryogenic vessel rather than aluminium 5083 as because, the strain is more in aluminium designed vessel and nickel copper is capable of withstanding at high pressure environment.

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