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DESIGN AND ANALYSIS OF LARGE TRANSPORTABLE VACUUM INSULATED CRYOGENIC VESSEL

GUMMA SRINIVASA RAO [1], Kondapa Naidu.B[2] S.C.V.Ramana Murthy naidu[3],
[1]M.Tech, student, Department of Mechanical Engineering, Kallam HaranadhaReddy Institute of Technology
[2]Assistant professor, Department of Mechanical Engineering, Kallam HaranadhaReddy Institute of Technology
[3] Professor & HOD, Department of Mechanical Engineering, Kallam HaranadhaReddy Institute of Technology

Abstract

The denotation “cryogenics” is defined as the study of a liquefied gas at very low temperature (below −150°C), as well as how materials perform at the aforementioned temperature. In this case, the cryogenic fluid is methane, which presents very good flammable qualities allowing it to be used as a new fuel and energy source

This project is deals with design and analyses a large transportable vacuum insulated cryogenic vessel that will be attached to a truck in order to keep, maintain and transport by road liquid methane

Considerations such as different pressure loads, dimensions, materials as well as their mechanical properties, constraints, masses, insulation systems and weather-environmental conditions are made in the mechanical analysis. The CAD software solid works is used to visualize the models for the chosen designs. In addition, the finite element module ANSYS WORKBENCH is used to obtain results of mechanical analyses in order to determine if the stresses are within margins. And also to increase the performance of the object here pressure vessels inner walls modified with different sizes and calculated their results and comparing with existing wall dimensions, finally thesis conclude with optimum pressure vessel inner wall dimensions with optimum material properties, with suitable graphs and tables,
Cad tool: solid works
Cae tool: Ansys workbench

INTRODUCTION

The denotation “cryogenics” is defined as the study of a liquefied gas at very low temperature (below −150°C), as well as how materials perform at the aforementioned temperature. In this case, the cryogenic fluid is methane, which presents very good flammable qualities allowing it to be used as a new fuel and energy source. By being liquefied, methane reduces its volume approximately 580 times at room pressure (1 bar), which makes it possible to transport a large quantity of methane in a small tank, which can be transported by a truck.

Cryogenic vessels could be transportable (by road, by train or by boat) or stationary (set on a gas plant, for instance). Moreover, vessels could be insulated by vacuum or by special insulation material (foam, for example).

This project is aimed at the design and analysis of a transportable cryogenic vessel composed of several parts. Methane is kept in an inner vessel covered by an outer jacket of the same shape. Between both vessels, a vacuum insulation system is located. There are also beams which are used as connections between the inner vessel and the outer jacket and these are designed, analyzed and optimized in order to obtain stress values within margins. Apart from this, the project also addresses the frame to which vessels are attached, as well as its supports, which are the connections between the vessels and the frame. Finally, pipes and valves are taken into consideration in order to complete the design of the cryogenic vessel.

This project is structured around two parts. The first part contains a background on methane, the truck with the hook-lift mechanism and the insulation system. The second part focuses on the design and finite element analysis of the cryogenic vessel assembly.

2. BACKGROUND INFORMATION

The vessel is intended to carry methane. Therefore, in order to gain a better knowledge of this element, some characteristics are mentioned bellow. Since the properties of methane affect the design and analysis of the vessel, a truck with a hook-lift mechanism is intended to transport the vessel and thus an overview of them is studied.

Vacuum is selected as the insulation system. There are various kinds of methods for vacuum insulation. The description of these appears below.

2.1. Methane

Methane is a chemical compound with the chemical formula CH_4. It is the principal component of natural gas (about 87 % by volume). The relative abundance of methane makes it an attractive fuel. However, given that methane is a gas at normal temperature and pressure, it is difficult to transport. Methane in a gas state is flammable only when its concentration in air fluctuates between 5 and 15 %. Liquid methane does not burn unless subjected to a high pressure of 4 – 5 atmospheres normally.

Regarding potential health hazards, methane is not toxic. However, it is highly flammable and may form explosive mixtures on contact with air. It is violently reactive with oxidizers, halogens and some halogen-containing compounds. It is also suffocating and it may displace oxygen in an enclosed space. A decrease in its oxygen concentration down to or below 19.5 % by displacement may result in asphyxia.

Methane is important for the generation of electricity by burning it as a fuel in a gas turbine or steam boiler. Compared to other hydrocarbon fuels, burning methane produces less carbon dioxide for each unit of released heat. With 891 kJ/mol, methane's heat of combustion is lower than any other hydrocarbon, but the ratio of the heat of combustion regarding the molecular mass (16 g/mol) shows that methane, being the simplest hydrocarbon, produces more heat per mass unit (55.7 kJ/g) than other hydrocarbons. In many cities, methane is distributed into homes for domestic heating and cooking purposes. In this context it is usually known as natural gas and it is considered to have an energy content of 39 MJ/m3 at a temperature of 0 ºC and a pressure of 1 bar.

Methane in the form of compressed natural gas is used as a vehicle fuel and it is claimed to be more environmentally friendly than other fossil fuels such as gasoline/petrol and diesel.

Methane is often kept in the transportable vessel in a liquid state (denoted “liquefied methane gas”, LMG), given that it is possible to keep more liquefied methane than gas methane within the same volume space, as the ratio of volumes is 1/580. Methane is in a liquid state at a temperature of -160 ºC and a pressure of 1 bar. It has a density of 415 kg/m3. Methane is also less dangerous in a liquid state regarding fire and explosions matters.

LITERATURE REVIEW

Shafique M.A. Khan presents analysis results of stress distributions in a horizontal pressure vessel and the saddle supports. The results are obtained from a 3D finite element analysis. He showed the stress distribution in the pressure vessel, the results provide details of stress distribution in different parts of the saddle separately, i.e. wear, web, flange and base plates. A value of 0.25 for the ratio A/L is favored for minimum stresses in the pressure vessel and the saddle. The slenderness ratio (L/R) of less than 16 is found to generate minimum stresses in the pressure vessel and the saddle. The highly stressed area, beside the pressure vessel at the saddle horn, is the flange plate of the saddle.

Aceves S.M. et al shows an evaluation of the applicability of the insulated pressure vessels for light duty vehicles. The paper shows an evaluation of evaporative losses and insulation requirements and a description of the current analysis and experimental plans for testing insulated pressure vessels. The most important results can be summarized that. Insulated pressure vessels do not lose any hydrogen for daily driving distances of more than 10 km/day for a 17 km/l energy equivalent fuel economy. Since almost all cars are driven for longer distances, most cars would never lose any hydrogen. Losses during long periods of parking are small. Due to their high pressure capacity, these vessels retain about a third of its full charge even after a very long period of inactivity, so that the owner would not risk running out of fuel. Also previous testing has determined the potential of low-temperature operation of commercially available aluminum -lined wrapped vessels for a limited number of cycles. Further testing will extend the number of cycles to the values required for a light-duty vehicle. Additional analysis and testing will help in determining the safety and applicability of insulated pressure vessels for hydrogen storage in light-duty vehicle.

Problem definition

Cryogenic engineering is concerned with low temperatures and the equipment used in Producing, storing and using of fluids at low temperatures. Due to the increasing use of cryogenic fluids in industrial applications, the storage and transport of cryogenic fluids has become a necessity. Because of low temperatures, the storage of cryogenic fluids is difficult. Cryogenic fluids must be maintained at low temperatures and high pressures, otherwise the change of phase may occur, and storage of cryogenic fluids is possible with insulated chambers. Mainly, damage of inner vessel's surge plates and edges are happened due to uneven conditions of transportation leads in creating variable pressure impacts inside the walls and plates. This creates the deformation of tank's edges and surgical plates which are not repairable for that application.

High pressure with high heat transfer rate design/materials can cause the damage of the object, so whatever the material it is made up of that should reduce the heat transfer from internal to external, so that the cryogenic vessel can maintain minimum temperature -170*C

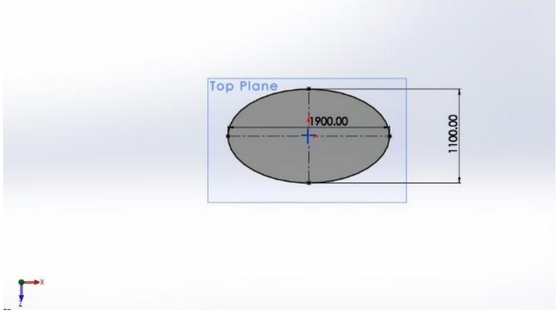
Aim of the project

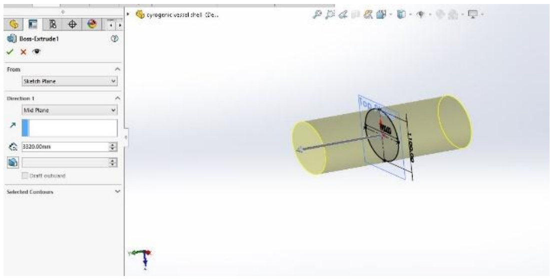
The main aim of the project is to reduce the internal stress values of cryogenic pressure vessel by changing materials/ inner walls dimensions, and also reduce the heat transfer rate from inside to outside, in order to achieve this here solid works were used to design or optimize the cryogenic vessels, and Ansys workbench were utilized to know the static and thermal behavior each material or design, finally thesis concluded with less amount of internal stress design with less amount of heat transfer rate materials,

Results to be calculated

Deformation, stress, strain, safety factor, total temperature, heat flux

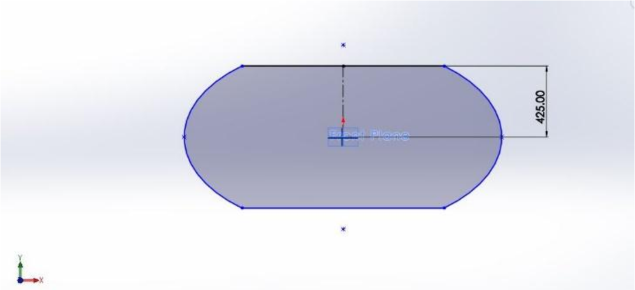
Designing process step by step



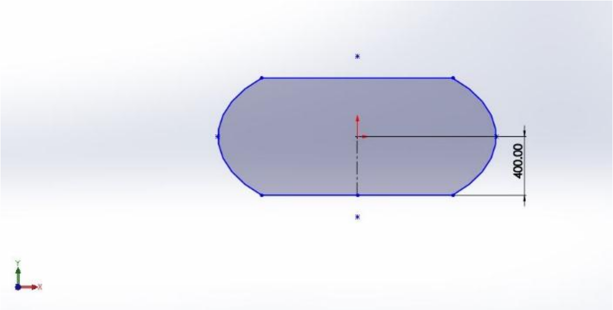


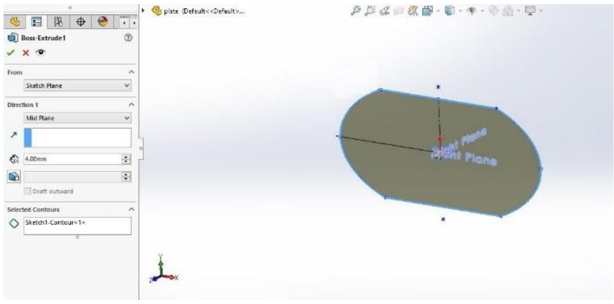
From
Sketch Plane
Direction 1
Mid Plane
3320.00mm
☐ Draft outward
Selected Contours

Design 1 inner wall

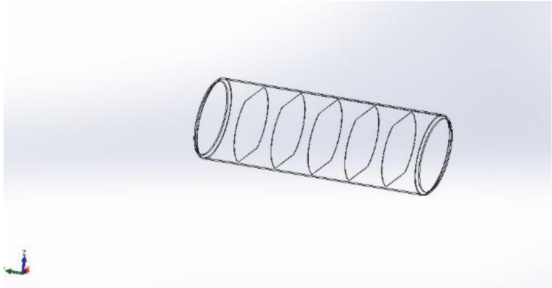


Design 2 inner wall





Boss-Extrude1
From
Sketch Plane
Direction 1
Mid Plane
4.00mm
Draft outward
Selected Contours
Sketch1-Contour<1>



Material selection

Steel

Young’s modulus: - 2.0*10^11 Pa

Poison ratio: 0.29

Density: 7850 Kg/m^3

Yield strength: 250Mpa

Sae-1020

Young’s modulus:- 1.96*10^11 Pa

Poison ratio: 0.292

Density: 7870Kg/m^3

Yield strength: 395.40 Mpa

Thermal conductivity: 52.1 w/m-k

SAE 1137

Ex: - 197*10^9 pa

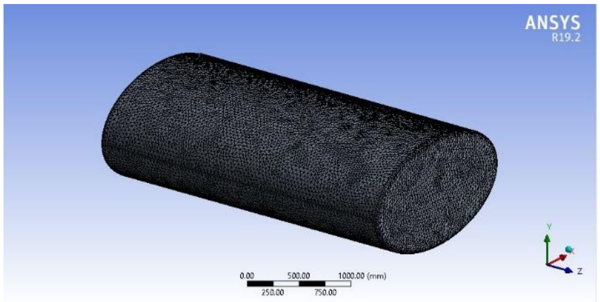
Poison ratio: 0.291

Density: 7800 kg/m^3

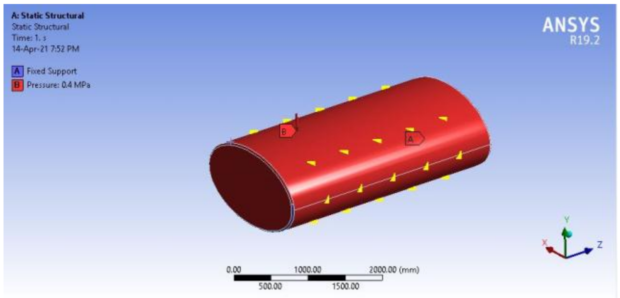
Yield strength: 496*10^6 pa

Analysis results

Meshing



Boundary conditions



Boundary conditions applied as in terms of pressure values, here applied pressure value is 0.4Mpa

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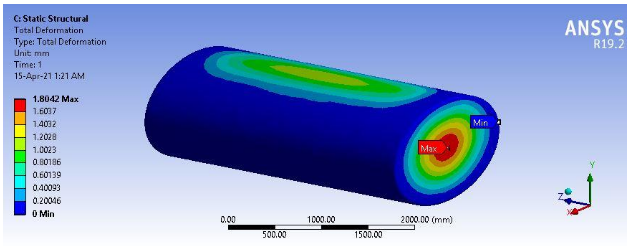
Results

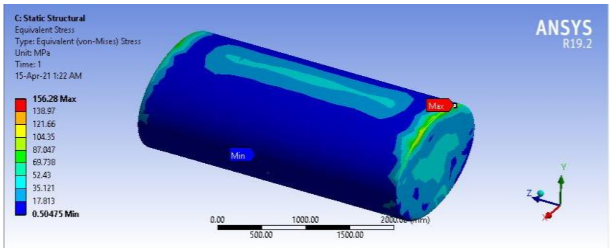
Design 1

Stainless steel

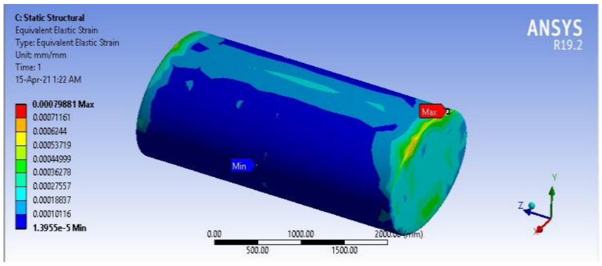
Deformation



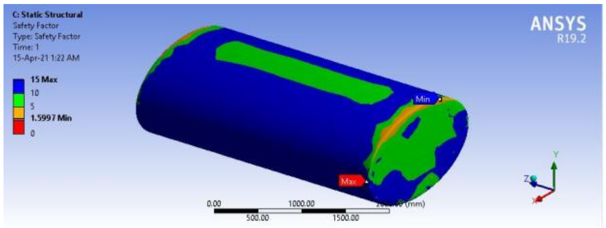
Stress



Strain

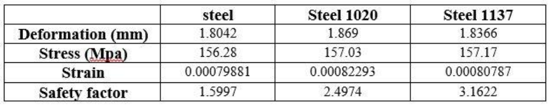


Safety factor



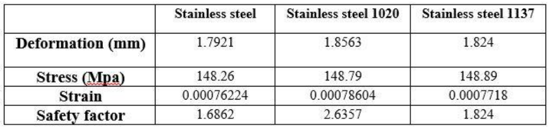
Tables

Design 1



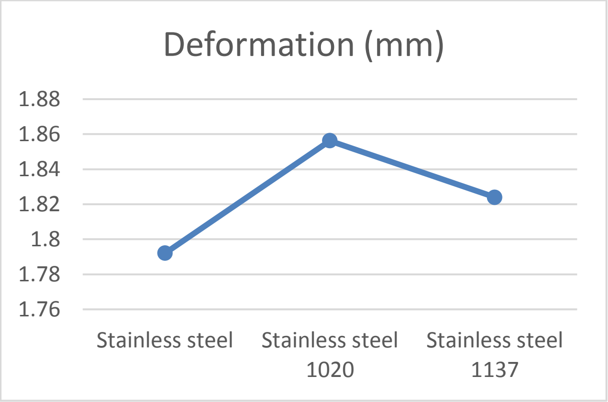
	steel	Steel 1020	Steel 1137
Deformation (mm)	1.8042	1.869	1.8366
Stress (Mpa)	156.28	157.03	157.17
Strain	0.00079881	0.00082293	0.00080787
Safety factor	1.5997	2.4974	3.1622

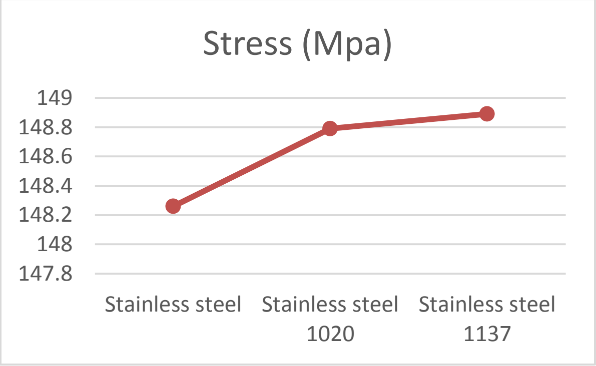
Design 2

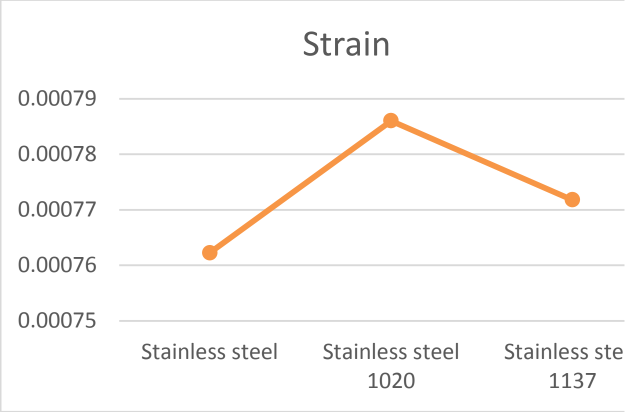


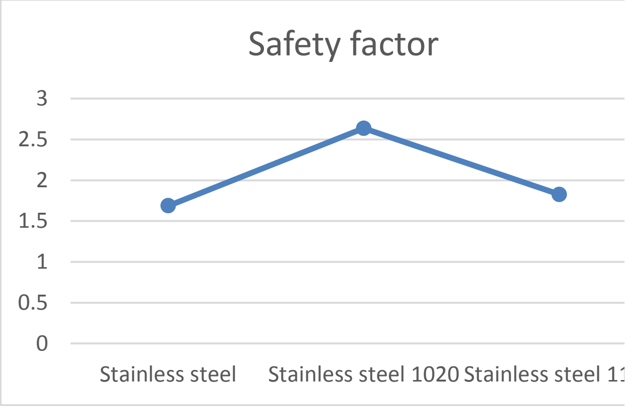
	Stainless steel	Stainless steel 1020	Stainless steel 1137
Deformation (mm)	1.7921	1.8563	1.824
Stress (Mpa)	148.26	148.79	148.89
Strain	0.00076224	0.00078604	0.0007718
Safety factor	1.6862	2.6357	1.824

Graphs









Thermal analysis results

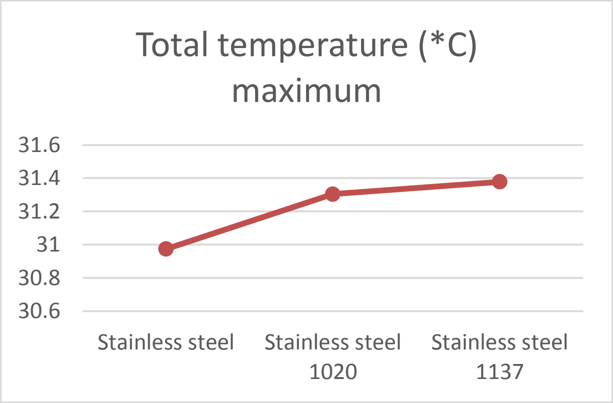
Design 1

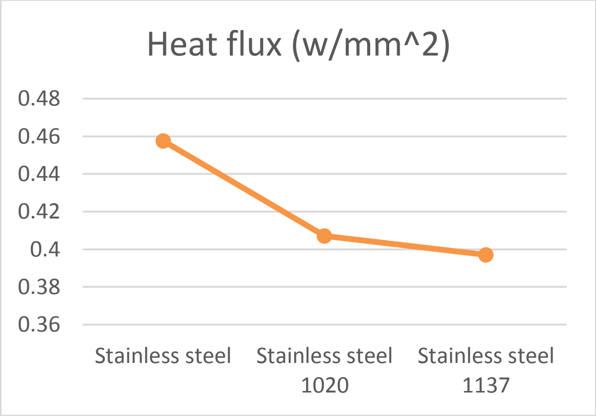
	Stainless steel	Stainless steel 1020	Stainless steel 1137
Total temperature (*C) maximum	32.591	33.029	33.126
Total temperature (*C) minimum	-170	-170	-170
Heat flux (w/mm^2)	0.46162	0.4129	0.40323

Design 2

	Stainless steel	Stainless steel 1020	Stainless steel 1137
Total temperature (*C) maximum	30.974	31.304	31.378
Total temperature (*C) minimum	-170	-170	-170
Heat flux (w/mm^2)	0.45756	0.40706	0.39702

Graphs





CONCLUSION

In this thesis cryogenic pressure vessel assemble model designed with the help of solid works, and analyzed with static and thermal boundary conditions with the help of Ansys workbench tool, here stainless steel material is considered as existing material, and stainless steel 1020, stainless steel 1137, were consider as new materials, the main aim of the project is to reduce the internal stress values, and also maintain internal temperature as low as possible to avoid explosions, to do this here inner walls dimensions modified and calculated results like deformation, stress, strain, safety factor values along with total temperature distribution of the object and their heat transfer rate,

In this thesis 2 internal wall designs (850mm minor axis wall, 800mm minor axis), were analyzed, when minor axis wall dimensions 800mm the internal stress values were reduced and the strength of the object is increased, from thermal analysis results both objects were maintains minimum temperature as -170*C but among all stainless steel 1137 material with minor axis 800mm cryogenic pressure vessel is having less amount of heat transfer rate values, less heat transfer rate means less amount of heat transfer from outside to inside walls, so that expositions, were avoided by these changes, finally thesis conclude with steel 1137 with 800mm minor axis walls cryogenic pressure vessels is having high safety values, and it increase the performance and durability of the object.

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