Implementation of a Large Transportable Vacuum Insulated Cryogenic Vessel

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Abstract: Technical gases turns into liquid in enormously low temperature ranging - 200°C and really high strain what makes that transportation instruments have got to perform very strict requirement. Cryogenic vessel is effectively saying insulated strain vessel which is used to store cryogenic liquid at cryogenic temperature which is –162C. Presented paper suggests designing side of the convenient cryogenic vessel for storing and transporting the cryogenic beverages like LNG for Indian rail conditions. Mobile vessel which is the object of design is a two shell tank with vacuum and layer insulation between shells container. It's assigned for see, railway and road transport and has got to follow all of necessities for such transportation programs. Necessities for such tank are enclosed in normal ISO 1496-3 which offers with freight containers and average EN13530-2 that describes vacuum, cryogenic vessels. Vessel will designed for the truck which is customarily used in industries & known as dumper. So that vessel can also be transported comfortably on this truck from one place to one other location. No distinctive vessel truck is required for transportation. Goal of this paper design cryogenic vessel which is diminish the hole between the stationary and moveable cryogenic vessel by way of designing vessel which is able to full fill both the requirement.

Keywords-Methane, TransportableVacuum Insulated Cryogenic Vessel.

I. INTRODUCTION

The denotation “cryogenics” is outlined as the learnof a liquefied fuel at very low temperature (beneath−a hundred and 50°C), as well as how substances participate in on theaforementioned temperature. At cryogenictemperature all gases are in liquefied kind. Forillustration at -162c temp. Methane is in liquefied form and it has 580 instances much less quantity then it is atroom temperature. So it's viable to movegiant range of methane in small tank.The cryogenic fluid is methane, which offersvery good flammable qualities enabling it to beused as a new gas and energy supply. It's utilized innumbers of industries as fuel in boilers or inchemical industries. The vessel is intended to carry methane. Therefore, in order to gain a better data 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.

Methane is a chemical compound with the chemical formula CH_4 [3]. 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 891kJ/mol, methane's heat of combustion is lower than any other hydrocarbon, but the ratio of the heat of combustion regarding the molecular mass (16g/mol) shows that methane, being the simplest hydrocarbon, produces more heat per mass unit (55.7kJ/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 39MJ/m3 at a temperature of 0 ºC and a pressure of 1bar.

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 415kg/m3. Methane is also less dangerous in a liquid state regarding fire and explosions matters.

So this paper prescribe design a vacuum insulatedcryogenic vessel with different supportivecomponent. This vessel is designed according tocryogenic standard like ISO 1496-3 & EN13530.Mathematic calculation is carried out for forces andthickness of different parameters according tostandards. Modeling is carried out on softwarepro-e.

II. RELATED WORK

It is necessary to find a truck which fulfills therequirements regarding dimensions, Maximumpayload and the possibility of attaching a hook-liftmechanism onto it, to load and unload the vesselon the truck chassis.

The chosen truck is the TATA 4x2 Truck, whichbelongs to the TATA FM13 range [4]. Its maindimensions are shown in figure 1 and some otherspecifications of the truck are listed below.

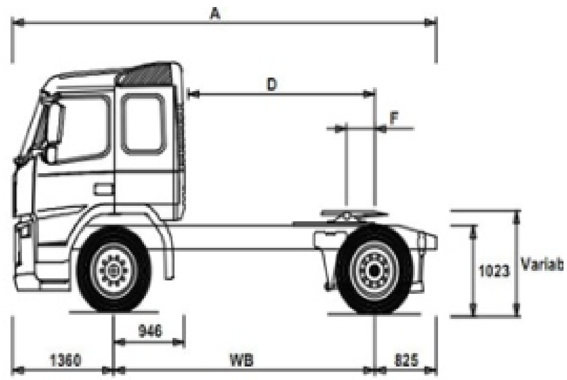


Figure: 1 Dimensions of the TATA4x2

Chassis dimensions:

- Wheelbase (WB): 3600 mm
- Overall chassis length (A): 7137 mm
  - Centre of rear axle to back of cab (D): 2604 mm
  - Theoretical wheelbase (T): 4285 mm

Plated weights:

- Gross vehicle weight: 34000 kg
- Gross combination weight: 44000 kg
- Maximum payload: 10000 kg

III. THEORETICAL CALCULATION

A. Design of Inner vessel:

Requirements for such tank are enclosed instandard ISO 1496-3 which deals with freightcontainers and standard EN13530-2 that describesvacuum in cryogenic vessels.The standards EN13530-2 defines that vesselswhich are to be filled equal or less than 80%should be fitted with surge plates to provide vesselstability and limit dynamic loads. Additionallysurge plates area has to be at least 70% of crosssection of the vessel and volume between surgeplates shall be not higher than 7.5m3.Structure ofthe vessel as well as the surge plate should resist oflongitudinal acceleration of 2g.For given configuration of truck and frame the bestsize occupied on it is length 3000 mm, width 1800mm and height of 1100 mm (data available frompressure vessel design).For stress calculation for this dimension is done onbase of Clavarino's equation according to used forthe pressure vessel.[5]

$$t = r_i[\sqrt[2]{\frac{\sigma_t + (1-2\mu)P}{\sigma_t - (1+\mu)P}} - 1]$$

σ_t = Tensile stress N/mm^2

$\mu = possion's\ ratio$

P= design pressure

σ_t= yield stress= 0.8σ_t

r= radius of the vessel (minor axis radius in case of the elliptical vessel)

B. Design pressure calculation:

Three pressures arerequiring for the calculation ofdesign pressure. This pressure can be calculatedbased on Swedish standard SS-EN 13530, Part 2.

Notation:

P_t= Test pressure

P_s= Maximum allowable pressure

P_c= Pressure during operation

P_l= Pressure exerted by the mass of the liquidcontents when the vessel is filled to capacity l litter

P= Internal design pressure (this pressure is usedfor designing cryogenic vessel)

The maximum allowable pressure in case of naturalgas is 1 bar but we will take 4 bar. For calculating $P_l$required mass of the liquid when filled up to Llevel for our problem is 0.14 bar (available fromstandard catalogue)

The 1.5 bar added in both equations comes fromthe effect of the vacuum. Since vacuum has nopressure, it is necessary to add an extra pressure of1.5 bar acting on the outer surface of the innervessel in the opposite direction of the atmosphericpressure direction in order to equilibrate thegradient of pressures between the vacuum and theinside of the inner vessel. This extra pressure, inturn, comes into the inner vessel following thesame direction as the other pressures (test pressureand pressure during operation).

According to the Swedish standard SS-EN 13530,Part 2, the internal design pressure shall be thegreater of and corrected for operatingconditions (K_{20}/K_t) to take into account the cold Properties of the used material

C. Outer jacket Design

The outer jacket is intended to hold the inner vesseland the vacuum insulation system. It presents thesame shape as the inner vessel; therefore itscharacteristics are similar.The chosen material for this part is the AISI 1040carbon steel. It is selected because it has high yieldstrength (353 MPa), which is translated for asmaller thickness than if a weaker material wereused.Inner and outer vessel is connected by beams sothat total weight is transferred from inner vessel toouter vessel throw this beams.

D. Thickness of outer beam

Thickness is mostly taken as 1.5t to 2.5t because itis exposed in the outside so that it required higherthickness then inner vessel.

E. Surge plate;

In the internal part of this vessel there are fivesurge plates that reduce the effect of moving wavesof liquid while the truck accelerates. The study ofsurge plate is carried out by E. Lisowski[3]. Thedesign of surge plate and its effect on wavepropagation is carried out by him.During designing of surge plate some rule isrequired to follow according to the ISO Standardand EN 13458-2 (2002), sated bellow

1) Surge plate follows same shape as vessel butit is horizontal at top and bottom because atbottom to make possible to fill the vesselfrom one position and at top part for lettinggases flow through it.

2) The surge plates cover an area ofapproximately 70 % of the cross-sectionarea of the inner vessel, according to theSwedish standard SS-EN 13530, Part 2.

The force applied on surge plate is 2g. So thedesign is done on basis of it. Force is assumed touniformly distribute through the plate.

F. Beam Design:

The beams are intended to join the inner vessel andthe outer jacket, in other words, to keep themattached. As a result, they transmit the forces fromone to the other. The distribution around thevessels. Beams can be classified in two groups:firstly, the group formed by the beams which areon the top and on the bottom of the inner vessel;and secondly, those which are on the sides of it.Regarding the first group, the total number ofbeams is 16, distributed symmetrically in fourdifferent rows: two of them on the top of the innervessel and the other two on the bottom of it.

Here buckling stress is avoided because length of beam is much smaller then diameter of beam. Thickness of beam obtained by maximum force that can be transferred by beam. It is the weight of vessel distributed over the different section of beam. It depends upon the location of the beam between inner and outer vessel so for this different analysis is carried out for different location of beam and tried to find out best arrangement of different beam.

IV. 3D MODELING

Certain hypothesis is formulated to carry outdesign procedure.

 All parts are modeled as surface models inorder to idealize them with shell elements inthe finite element analysis.

 All pipes and all connections between theinner vessel and the outer jacket areidealized as beams with a specified crosssection for each one of them.

 Since all mechanical analyses are made forthe whole unit, it is necessary to setconstraints in one of the parts. As the frameis the part in contact with the truck, theframe is the one that has the constraints.These constraints are located in one place oranother depending on the position of theassembly.

 In finite element analysis, considerationssuch as “numerical singularities” (they comeup in the meeting point of several sharpedges or corners) and “incompatibilities”(locations with largeconcentration ofstresses that come from the union orconnection of the beam idealization with theshell idealization) are taken into account,but they are ignored due to the fact that theyare not physically real. Regardingincompatibilities, the finite element moduledoes not take into account the whole sectionof the beam, rather only taking intoconsideration one single point. Thus, thesame stress values are obtained by usingdifferent beam crosssection values withinthe same conditions (loads and constraints).

 The mechanical analysis of the completeassembly is performed with three differentloads. These loads are the gravity (9.81m/), an incoming pressure load of 2 baraffecting the outer surface of the outer jacketand an outgoing pressure load of 5 baraffecting the inner surface of the innervessel.

In each part, the value of the safety factor,which comes from the ratio between theyield strength and the maximum stressvalue, is given. The tensile strength is notconsidered for this calculation as criteria forfailure

 The union of each part with another issupposed to be obtained through weldingprocesses, which are considered as multipoint constraints. These constraints set thenodes of a surface to have the samedisplacement as the nodes of anothersurface. Thus, the final assembly isconsidered as one unit.

A. Inner Vessel Design:3D model of the inner vessel is shown in fig. 1with detailed drawing in appendix

B. Surge plate: In the internal part of this vessel there are fivesurge plates that reduce the effect of moving wavesof liquid while the truck accelerates. They have athickness of two millimeters and they are placedwith a distance between them of 550 mm.The shape of the surge plates follows the shape ofthe vessel but ends with horizontal edges at the topand bottom part.

C. Beams: The beams are intended to join the inner vessel andthe outer jacket, in other words, to keep themattached. As a result, they transmit the forces fromone to the other. The distribution around thevessels.Position of the initially beam is shown in fig.Beams can be classified in two groups: firstly, thegroup formed by the beams which are on the topand on the bottom of the inner vessel; andsecondly, those which are on the sides of it.Regarding the first group, the total number ofbeams is 16, distributed symmetrically in fourdifferent rows: two of them on the top of the innervessel and the other two on the bottom of it. Thedistance between each beam is 664 mm and eachone has an angle of inclination of 45° from thehorizontal symmetry plane of the inner vessel(front plane). Regarding the second group, the totalnumber of beams is 8, four on each side. They areplaced symmetrically around each surface and theyare perpendicular to the surfaces of the inner vesseland the outer jacket.

V. RESULTS AND DISCUSSIONS

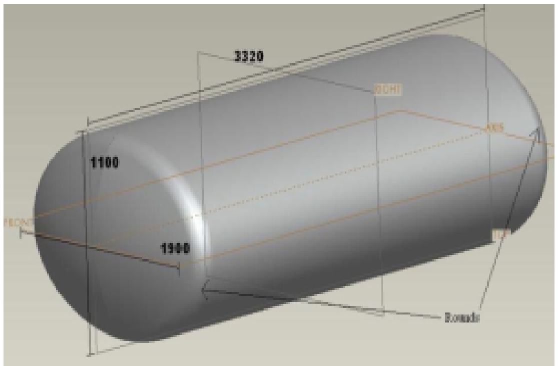


Figure: 2 Inner vesselThickness is 18 mm

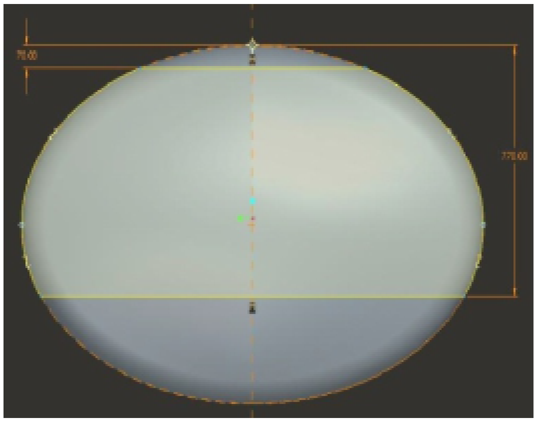


Figure: 3 Surge plate design

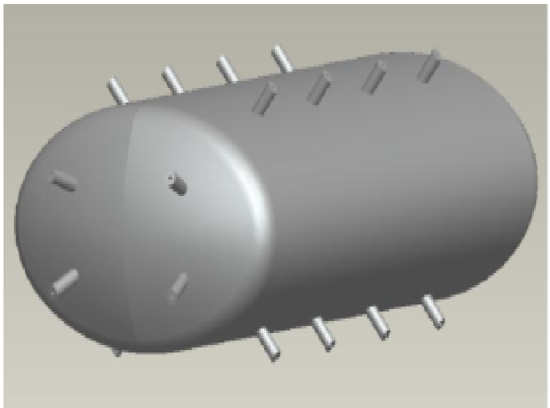


Figure: 4 Beam arrangement in inner vessel

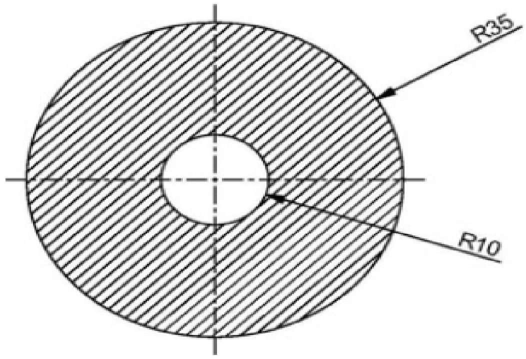
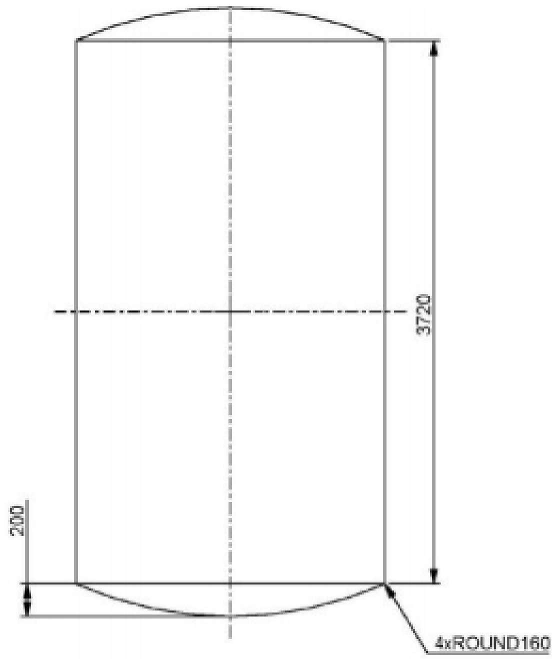


Figure: 5 Cross section area of pipe



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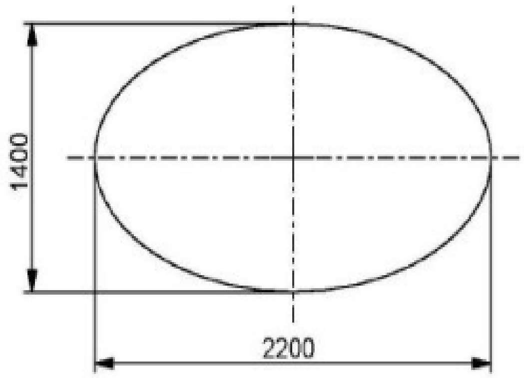

Figure: 6 Outer vessel

VI. CONCLUSION

Simulated options at more than a few nodes are validated with numerical options which can be particularly in excellent understanding and show the feasibility of the difficulty methodology.

O For the Hafnium diboride material the temperature distribution is from 2478°k to 2411.58°k and the distribution is natural showing the uniformity of the distribution over the entire nose cone.

O But for the Zirconium diboride material the temperature distribution just isn't identical and it's 2478°k at the skin of the TPS layer and indicates the resistance of the material in transferring the temperature for the remaining of the nose cone.

O From the simulated results the Hafnium diboride material shows the simpler distribution pattern and its heat flux values are also in promising stages than Zirconium diboride material.

O This can be extra evaluated for the transient thermal evaluation which will have extra options for the outlined drawback.

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