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Enactment of a Large Transportable Vacuum Insulated Cryogenic Vessel

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Abstract: Cryogenic engineering is apprehensive with low temperatures and the equipment used inproducing, storing and using of fluids at low temperatures. Due to the collective use of cryogenic fluids in industrial applications, the storage and transport of cryogenic fluids has become anecessity. Because of low temperatures, the storage of cryogenic fluids is problematic. Cryogenic fluidsmust be maintained at low temperatures and high pressures, otherwise the change of phase mayoccur, and storage of cryogenic fluids is possible with insulated chambers.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, Transportable Vacuum Insulated Cryogenic Vessel.

I. INTRODUCTION

Cryogenics is the science that addresses the production and effects of very low temperatures. The wordoriginates from the Greek words 'kryos' meaning "frost" and 'genic' meaning "to produce." Under such adefinition it could be used to include all temperatures below the freezing point of water (0 C). However,Prof. Kamerlingh Onnes of the University of Leiden in the Netherlands first used the word in 1894 todescribe the art and science of producing much lower temperatures. He used the word in reference to theliquefaction of permanent gases such as oxygen, nitrogen, hydrogen, and helium. Oxygen had beenliquefied at -183°C a few years earlier (in 1887), and a race was in progress to liquefy the remainingpermanent gases at even lower temperatures. The techniques employed in producing such lowtemperatures were quite different from those used somewhat earlier in the production of artificial ice. Inparticular, efficient heat exchangers are required to reach very low temperatures. According to the laws of Methane is a chemical compound with the chemical formula CH4 [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.

Molecules are in their lowest, but finite, energy state at absolute zero. Such a temperature is impossibleto reach because the input power required approaches infinity. However, temperatures within a fewbillionths of a degree above absolute zero have been achieved. Absolute zero is the zero of the absolute orthermodynamic temperature scale. It is equal to -273.15°C or -459.67°F. The metric or SI (InternationalSystem) absolute scale is known as the Kelvin scale whose unit is the kelvin (not Kelvin) which has thesame magnitude as the degree Celsius. The symbol for the Kelvin scale is K, as adopted by the 13thGeneral Council on Weights and Measures (CGPM) in 1968, and not K. Thus, 0 C equals 273.15 K.The production of cryogenic temperatures almost always utilizes the compression and expansion ofgases. In typical air liquefaction process the air is compressed, causing it to heat, and allowed to cool backto room temperature while still pressurized. The compressed air is further cooled in a heat exchangerbefore it is allowed to expand back to atmospheric pressure. The expansion causes the air to cool and aportion of it to liquefy. The remaining cooled gaseous portion is returned through the other side of the heatexchanger where it pre cools the incoming high-pressure air before returning to the compressor. The liquidportion is usually distilled to produce liquid oxygen, liquid nitrogen, and liquid argon other gases, such ashelium, are used in a similar process to produce even lower temperatures, but several stages of expansionare necessary.

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

Shafique M.A. Khan presents analysis results of stress distributions in a horizontal pressure vessel andthe saddle supports. The results are obtained from a 3D finite element analysis. He showed the stressdistribution in the pressure vessel, the results provide details of stress distribution in different parts ofthe saddle separately, i.e. wear, web, flange and base plates. A value of 0.25 for the ratio A/L is favoredfor minimum stresses in the pressure vessel and the saddle. The slenderness ratio (L/R) of less than 16 isfound 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 lightduty 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. Themost important results can be summarized that. Insulated pressure vessels do not lose any hydrogen fordaily driving distances of more than 10 km/day for a 17 km/l energy equivalent fuel economy. Sincealmost all cars are driven for longer distances, most cars would never lose any hydrogen. Losses duringlong periods of parking are small. Due to their high pressure capacity, these vessels retain about a thirdof its full charge even after a very long period of inactivity, so that the owner would not risk running outof fuel. Also previous testing has determined the potential of low-temperature operation of commerciallyavailable aluminium -lined wrapped vessels for a limited number of cycles. Further testing will extendthe number of cycles to the values required for a light-duty vehicle. Additional analysis and testing willhelp in determining the safety and applicability of insulated pressure vessels for hydrogen storage inlight-duty vehicle.

- Mr. Abdul Sayeed et al worked on solid structural analysis of vacuum chamber. The analysis is donefor electron microscopy applications, for scanning electron microscope it require vacuum atmospherefor viewing of the specimen. The specimen is to be viewed in vacuum. The vacuum level required forthat is in the range of 700 torr, which is less than atmospheric pressure lead to compressive forces on thechamber they made vacuum chamber model in Catia and Simulation is done in Ansys. The Vacuumchamber is safe from buckling failure as applied p is very small in comparison to max theoreticalbuckling pressure. Compressive yield strength of structural steel is greater than Von Mises stress iscalculated by solid structural analysis so it is safe from this criterion.

- Aceves S.M.et al. worked on high pressure and evalution of insulated pressure vessel for cryogenichydrogen storage. The work described in this paper directed at verifying that commercially availablepressure vessels can be safely used to store liquid hydrogen. This paper describes a series of tests whichare shown below, that have been done with aluminium lined, fiber-wrapped vessels to evaluate thedamage caused by low temperature operation. In FEM testing Cyclic, ultrasound and burst testing of thepressure vessels is being complemented with a finite element analysis, which will help to determine thecauses of any potential damage to the vessel during low temperature operation.

- N.Vukojeviæ et al presented Vertical pressure vessels according EN 13445 are supported on fourdifferent kind of supports. In paper is presented stress-strain analysis of pressure vessel supported bybrackets. Problems with supports are specially marked by great pressure vessels and without correctlychoosing, supports type can become potentially weak point in construction. The Results based onpresented analysis shown that great pressure vessel supported on bracket supports demonstrate poorsolution in relation to continual cofigutared supports (script supports). Bracket type of supports isunfavorable in case of initial crack failures with growth tendention. Results deviation between numericalexperimental analyses are implication of different wall thickness of pressure vessel made by forging.

- A.Th. Diamantoudis et al. tried comparative study for design by analysis and design by formula of acylinder to nozzle intersection has been made using different finite element techniques. The cylinder tonozzle intersection investigated is part of a typical vertical pressure vessel with a skirt support. For thestudy the commonly used ductile P355 steel alloy and the high strength steel alloy P500 QT wereconsidered. The application of Design by Analysis (DBA) leads to much less conservative designparameters. The high strength steel P500 is severely punished when Design by Formula (DBF) rules areapplied, instead of DBA methodology.

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.

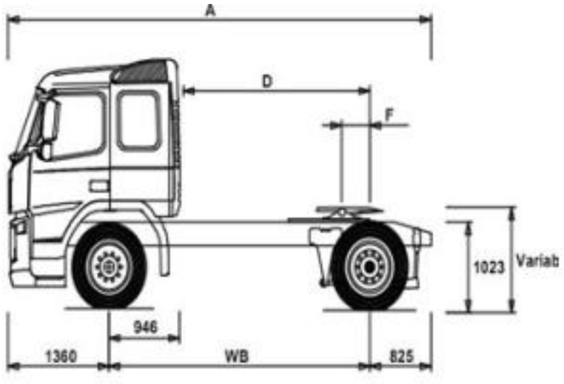


Figure: 1 Dimensions of the TATA4x2

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)

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

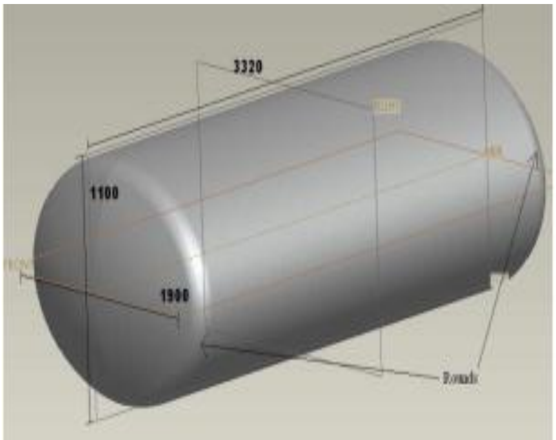


Figure: 2 Inner vesselThickness is 18 mm

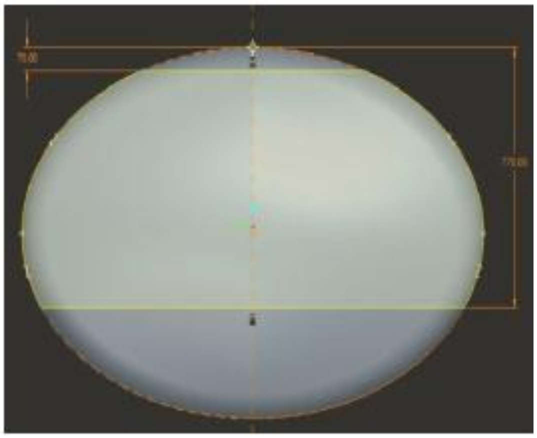


Figure: 3 Surge plate design

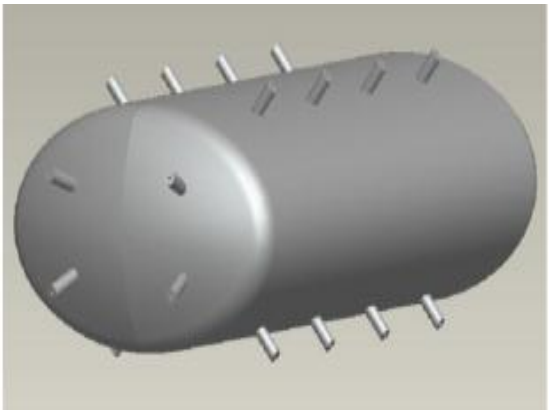


Figure: 4 Beam arrangement in inner vessel

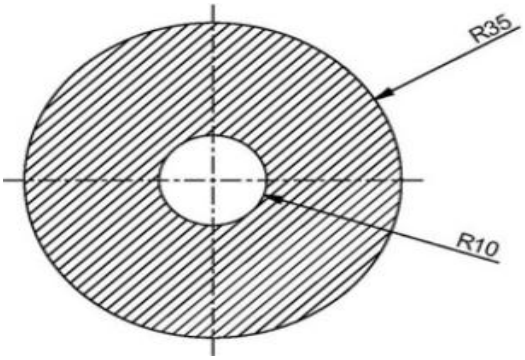
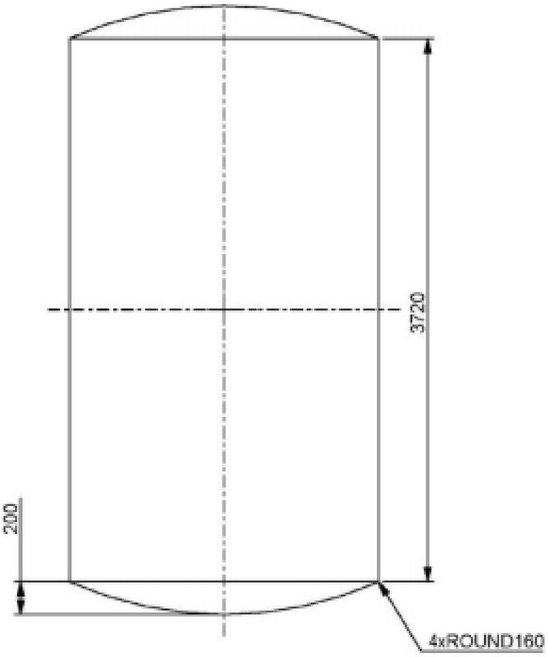


Figure: 5 Cross section area of pipe



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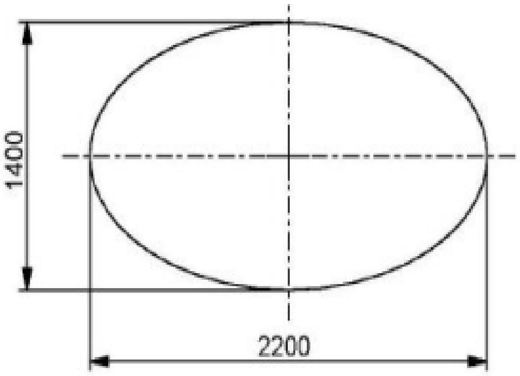

Figure: 6 Outer vessel

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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