Design and Analyses of the Insulated Cryogenic Vessel for Transport

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Abstract- **The Cryogenic vessels is small tank have been used for transport the large quantity of cryogenic fluid for example methane, by reduces its volume at atmospheric pressure and transport through road, train or boat. It is also used as storage tank for cryogenic fluid in gas plant. These vessels are insulated by vacuum or by special insulation material like foam to avoid the surrounding effects. This work included study, design and analyze a large transportable vacuum insulated cryogenic vessel that has been attached to a truck in order to keep, maintain and transport by road liquid methane at a temperature of -162 °C. In this work CAD software NX 10 is used to visualize the models for the chosen designs. In addition, the Finite element module Ansys is used to obtain results of mechanical analyses like von Mises stresses within margins. Every part of vessel has been designed and analyzed with good corrosion resistance material. It is conclude that the thickness of the outer jacket does not have higher than that of the inner vessel. It was possible to economize on material. The results of each part shows design is safe and suggested.**

Index Terms- **Cryogenic vessel, Jacket, Von Mises stress, CAD software.**

I. INTRODUCTION

The 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 work cryogenic fluid is taken as methane and it has very good flammable qualities allowing it to be used as a new fuel and energy source. It being liquefied and 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. This study 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 presented work 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 work 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.

The design aspects of cryogenic dewar vessel for liquid nitrogen [1], determine the vaporization of cryogenic liquid (liquid-Nitrogen) for various combinations of inner, outer and insulated materials. 3-D Modeling of storage vessel is done by using Pro-E 2001 software and analysis is made in 2-D modeling by using ansys software. By incorporating the FEM analysis of cryogenic fluid storage vessel of liquid nitrogen. 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 [2]. Cryogenic storage vessels are pressure vessels are used for storage cryogenic liquids with minimum heat in-leak into the vessel from the outside as far as possible. The challenge of design is to use such materials that do not lose their desirable properties at such a low temperature [3]. The liquid-hydrogen Dewar development conducted by various researchers. The current trends in liner material development are reviewed in the case that a liner is required to minimize or eliminate the loss of hydrogen fuel through permeation [4].

Design analysis of multi layered cryogenic shell, with optimum orientations; minimum mass under strength constraints for a cylinder subjected to axial loading for static analysis on the pressure vessel has been studied [5]. The modeling is carried out in Creo Parametric 2.0 and the analysis is carried out in ANSYS 15.0 solver. Static analysis and Thermal analysis has been done and also material optimization is done for enhancement. Different materials are analyzed. Taking weight into consideration and stress into account, S- glass epoxy for the outer structure with aluminum for the inner structure is comparably better than the other materials

The objective of work is included that study, design and analyze 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 at a temperature of -162 °C. For this work CAD software NX 10 is used to visualize the models for the chosen designs. In addition, the finite element module Ansys is used to obtain results of mechanical analyses in order to determine the stresses are within margins.

II. DESIGN AND MODELING OF THE PARTS OF THE CRYOGENIC VESSEL

This step focuses on the study of the parts of the cryogenic vessel assembly to be designed. They are frame that the cryogenic vessel is standing on it, main vessel which is composed of an inner vessel, having cryogenic fluid and outer jacket which covering the inner vessel, in addition four supports (attachment between the vessels and the frame), twenty four beams (separating the inner vessel and the outer jacket), three pipes for letting some flows of gas or air going in and out of the vessels and cabinet as shown in fig.1.The assembly is shown, some of the parts such as the inner vessel, the pipes, the valves and the beams are not visualized

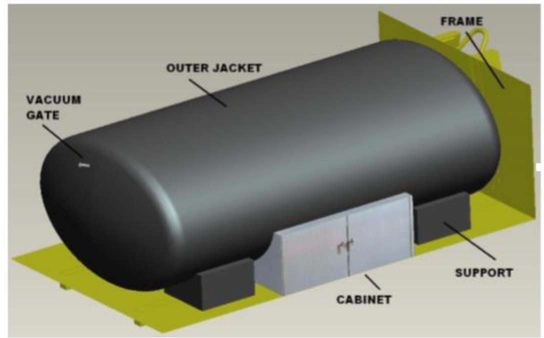

Fig.1: The parts of the Cryogenic Vessel

The design and modelling of each part of Cryogenic Vessel by using CAD software Pro/Engineer Wildfire 4.0. The frame is the part that connects the main vessel and its accessories to the truck. Its function is to carry and maintain the main vessel fixed to it. The modeling of the frame is shown fig.2.The design and modeling of parts of main vessel as follows.

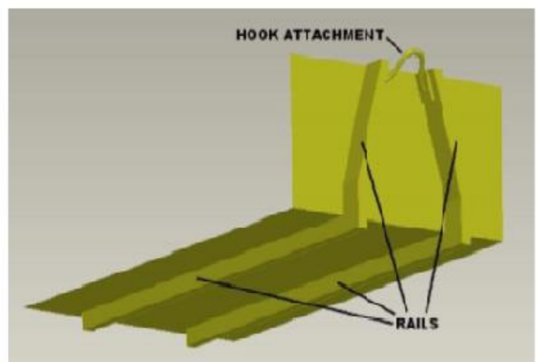

Fig.2 The modeling of the frame for Cryogenic Vessel

The main function of the inner vessel is to keep the methane at a temperature of -162ºC and it is symmetric shape. The main dimensions are a length of 3320 mm, a width of 1900 mm and a height of 1100 mm. The purpose of these features is that the rounds reduce the stress. The modeling of the inner vessel for Cryogenic Vessel as shown in fig.3. In the internal part of this vessel there are five surge plates that reduce the effect of moving waves of liquid while the truck accelerates. They have a thickness of two millimeters and they are placed with a distance of 550 mm In the internal part of this vessel there are five surge plates that reduce the effect of moving waves of liquid while the truck accelerates. They have a thickness of two millimetres and they are placed with a distance of 550 mm each other.

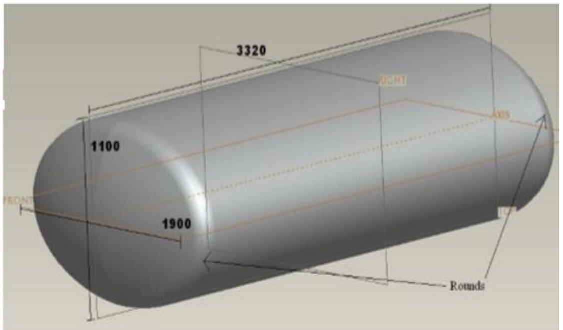

Fig.3. The modeling of the inner vessel for Cryogenic Vessel

The outer jacket purpose is to hold the inner vessel and provide the vacuum insulation system. Its shape is same as the inner vessel and characteristics are similar. The main dimensions are a length of 3720 mm, a width of 2200 mm and a height of 1400 mm. It is selected because it has high yield strength (353 MPa), which is translated for a smaller thickness than if a weaker material were used. Owing to the use of this material, the outer jacket has a mass of 1440 kg and it has a volume of 0.184 m^3.

The supports are intended to join the vessels to the frame. They hold the weight of the entire unit including methane weight. They also maintain the vessels fixed, stopping them from being displaced by the movement of the truck as shown in fig.1. The beams are intended to join the inner vessel and the outer jacket, and they transmit the forces from one to the other. The beams totally 24 each having weight of 4.65kg are placed around the circumference and top and bottom of vessels. There are three pipes are used for filling, draining and relief system.The modeling of the pipe for Cryogenic Vessel as shown in fig.4. The cabinet is used to cover and protect the piping and valve system and its modeling as shown in fig.5.Other parts that is different vavles and vacuum gate have been designed and modeled

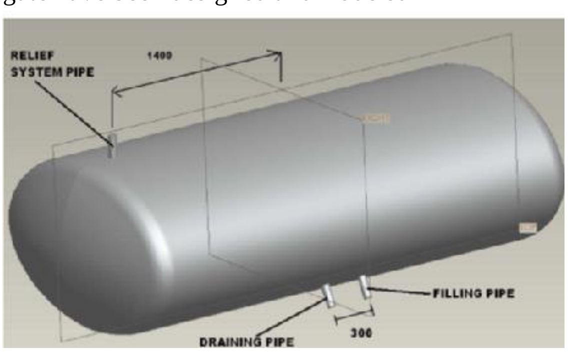

Fig.4. The modeling of the pipe for Cryogenic Vessel

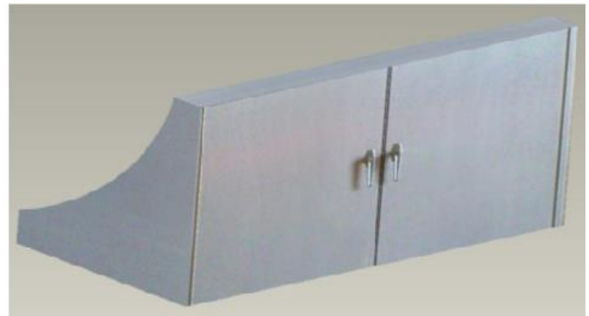

Fig.5. The modeling of the Cabinet for Cryogenic Vessel

III. ANALYSIS OF THE PARTS OF THE CRYOGENIC VESSEL

ANSYS is general-purpose finite element analysis (FEA) software package. Finite Element Analysis is a numerical method of deconstructing a complex system into very small pieces (of user-designated size) called elements. The software implements analysis for each part of Cryogenic Vessel. This analysis of the complete assembly is performed with three different loads. These loads are the gravity (9.81 m/s^2), an incoming pressure load of 2 bar affecting the outer surface of the outer jacket and an outgoing pressure load of 5 bar affecting the inner surface of the inner vessel. The Fig.6 shows the analysis of frame which is being loaded or unloaded. The results shows maximum value of von Mises stress is between 166.6 and 177.7 MPa for carbon steel.

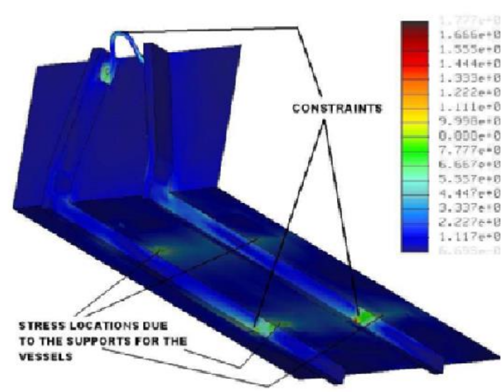

Fig.6. The Analysis of frame for Cryogenic Vessel

The inner vessel is made of the UNS S30400 stainless steel. This material is selected due to its good corrosion resistance. Its yield strength at room temperature is 290 MPa. At -196 ºC the metal has a yield strength of 386 MPa. The number of shell elements used for this simulation is 89. The fig.7 shows analysis of inner vessel and from which observe maximum stress location is placed on the rounded edge. The maximum Von Mises stress value on the rounded edge is 210 MPa.

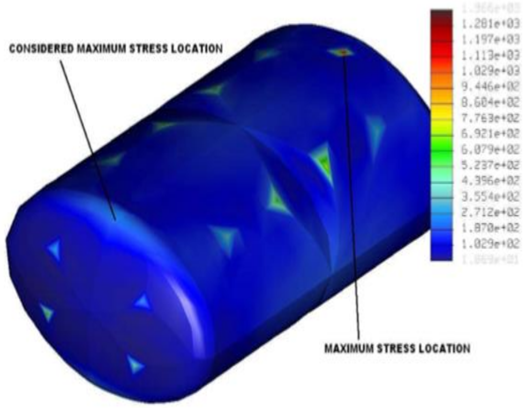

Fig.7. The Analysis of inner vessel for Cryogenic Vessel

The stress behaviour of the outer jacket is quite similar to the inner vessel, due to their similar shape. Therefore, the maximum stress location is placed on the rounded edges, and it has a von Mises stress value of 215 MPa as shown in fig.8.

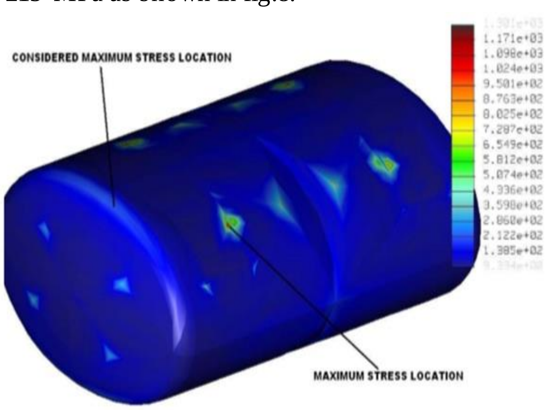

Fig.8. The Analysis of outer jacket for Cryogenic Vessel

Figure 9 shows the result of the finite element analysis for one of the supports, when the whole unit is in a vertical position.The considered maximum von Mises stress value is 91.7 MPa. The safety factor (in aspect of the yield strength) is 3.85. Apart from this, the maximum stress location is placed in the upper-left corner of the support, reaching a value of 184.6 MPa.

The maximum von Mises stress value for a beam from the analysis for first group is 232.1 MPa, and second group the maximum von Mises stress value is 20.7 MPa and therefore the safety factor (in aspect of the yield strength) is 14. The pipe analysis shows the maximum von Mises stress value occurs at two end points that is one at the union with the inner vessel and the other at the union with the outer jacket. The maximum von Mises stress value is 192 MPa and the safety factor is 1.51 for the relief system pipe.The maximum von Mises stress value is 157 MPa and the safety factor is 1.84 for the filling and draining pipes.

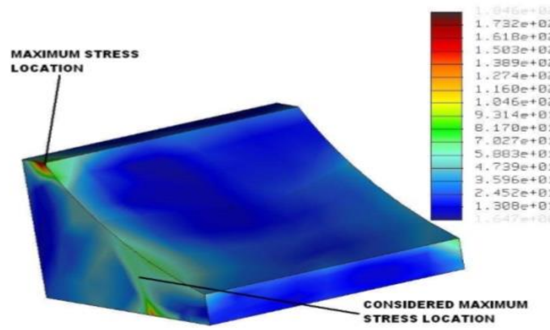

Fig.9. The Analysis of supports for Cryogenic Vessel

IV. CONCLUSIONS

Present senario, many new technologies and advances has been take place in the field of energy. Regarding cryogenics, it is easy to find elements such as cryogenic fluid hydrogen, oxygen or argon, but the use of methane as cryogenic gas has resulted in the appearance of a new way of obtaining high quality energy for different applications. The use of liquefied methane is a fairly new procedure, it has been in development for several years and therefore, meets the requirements of the standards institutes. Referring to this cryogenic vessel and apart from the fact that it has been analysed and designed to transport liquid methane at a temperature of -162 °C and attached to a truck, it can also be used as a stationary vessel, due to the fact that the frame is part of the entire unit and this is the part allowing the vessel to be loaded or unloaded. Therefore, in the case where the customer considers it appropriate, the whole unit can be unloaded and kept somewhere, so that it would be ready to be used again without losing any of its mechanical properties, thanks to the chosen materials and its insulation system. It can be said that the sum of each one of the parts constitutes the whole unit resulting from welding processes between the parts that are in contact with each other. This welding attachment is explained by the loading and unloading process of the unit.

The hooklift mechanism moves the unit into non-desirable situations, that is, angled positions (as the desirable position is the horizontal). In these situations, the unit has to be perfectly as well as strongly attached. Otherwise, it would break and cause irreparable damage. Concerning the design, it had to meet the appropriate requirements for the truck in question. These requirements included dimensions (the whole unit would be able to fit into the truck) and the maximum payload (maximum weight that the truck could carry), which had a value of 10 tons. Once the mass of every part was known, it was possible to know the total mass of the entire unit, taking into account the mass of the maximum quantity of liquid methane which was inside the inner vessel. This total mass reached a value of 8.5 tons, which gave a margin of 1.5 tons with respect to that maximum payload.Regarding materials, the same material could have been used for every part. Nevertheless, not every part works under the same conditions, so it was better to choose the appropriate one for each part. Materials could be divided into two groups: the ones that are directly exposed to a very low temperature and the others that are not directly exposed to a very low temperature. Thus, a material with a very good corrosion resistance (stainless steel) was chosen, as well as another material which did not have to present such corrosion resistance but fulfilled some other basic mechanical requirements (carbon steel). To conclude, given that the thickness of the outer jacket does not have to be as high as that of the inner vessel, it was possible to economize on material. With regard to mechanical analyses, each part was analysed independently as part of the whole assembly. In both cases all parts held perfectly under all the stresses they suffered when loads (gravity, an incoming pressure load of 2 bar affecting the outer jacket and an outgoing pressure load of 5 bar affecting the inner vessel) and constraints were applied.

Regarding safety factors in aspect of the yield strength, those of the inner vessel and the outer jacket seem to be low. However, they come from narrow locations where the used software is not very accurate. By taking a look at big locations one could observe some stresses much further away from the yield strengths in question. Anyway, this report has shown that every part works properly, as expected.

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