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DEVELOPMENT OF REDUCING BOIL OFF LOSSES IN LNG TRANSPORTATION USING POLYAMIDE AS SUPPORTING MATERIAL

K. Eqbert
Assistant Professor
Noorul Islam Centre for Higher Education
Kumaracoil – 629180, Tamilnadu, India

M. Dev Anand
Professor and Director Research
Noorul Islam Centre for Higher Education
Kumaracoil – 629180, Tamilnadu, India

ABSTRACT

Natural gas is being hailed as alternative energy sources for petroleum, because it is almost no emissions of pollutants in the environment. Reserves are located far from customer area this necessitates their storage and transportation. Liquefying of gas to the cryogenic temperature is cost effective since it decreases the volume by a factor of more than 600. At the atmospheric pressure, the liquefaction temperature of LNG is under minus 163 degree Celsius. Delivering of liquefied LNG to terminals by road or rail transport is one of the simplest solutions of this problem. This kind of transport is possible only with using suitable tanks with the adequate insulation and fulfilling the transport requirements. For transportation LNG can be stored at -163°C, boil-off losses are normally occurs. Many scientific researchers were carrying out investigations on high insulating-power materials. The construction of storage tank hastwowall with vacuum in between them. Distance between walls is provided by system of supporting blocks made of plastic. This paper presents problem of heat leak between the walls and the supporting blocks. The investigations were carried out mathematically and, using ANSYS software.

Key words: Polyamide, Heat Transfer, Cryogenic, Transport, LNG

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I. INTRODUCTION

The intemperate use of fossil fuels has led to gradually increasing drastic environmental pollution and energy crisis. Numerous research works have recently been carried out on looking for renewable resources as replacement for conventional fossil fuels. Natural Gas has been recognized as the superior option for the future energy industry because of the characteristics of unlimited supply, zero-emission of greenhouse gases, and high energy efficiency. Natural gas storage has become one of the predominant technical barriers limiting the widespread use of Natural gas energy. It contains mainly about 90% methane, ethane and trace amounts of nitrogen and carbon dioxide. However methane is difficult to transport at normal temperature and pressure, because it is in gas. Under Liquefied condition natural gas is a better form for the transportation and storage of natural gas. Liquefied natural gas (LNG) is produced by cooling natural gas with liquid nitrogen to -160°C under the normal atmospheric pressure. The volume of the LNG will be reduced to $1/600^{th}$ of its original volume. Thus, LNG is the format for transportation and storage of natural gas.

Storage and transportation of NG in liquefied condition is a difficult task and require high cost. It requires less weight with good insulating properties for long term storage. By the usage of advanced materials, structural concepts and finite element method is an effort to reduce the overall weight of the tank and reduce the boil off. LNG storage tanks have double containers, where the inner contains LNG and the outer container contains insulation materials [11 and 12]. In the present study we performed temperature gradient study on a double-walled, insulated cylindrical cryogenic tank wherein determine boil off rate.

2. CONSTRUCTION OF TANK

The construction of the multi walled storage tank was shown in Figure.1. It consists of inner vessel, outer vessel, supporting block and multiwall super insulation.

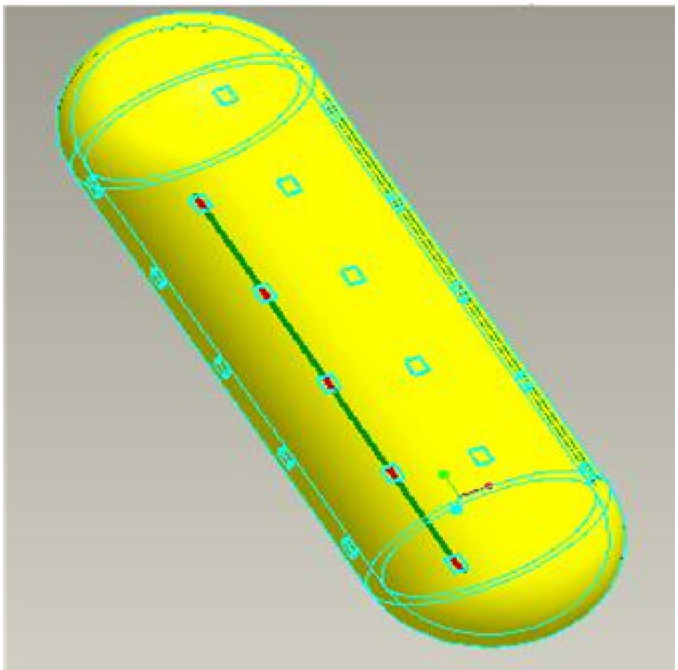

Figure 1 Assembled View of the Cryogenic Tank

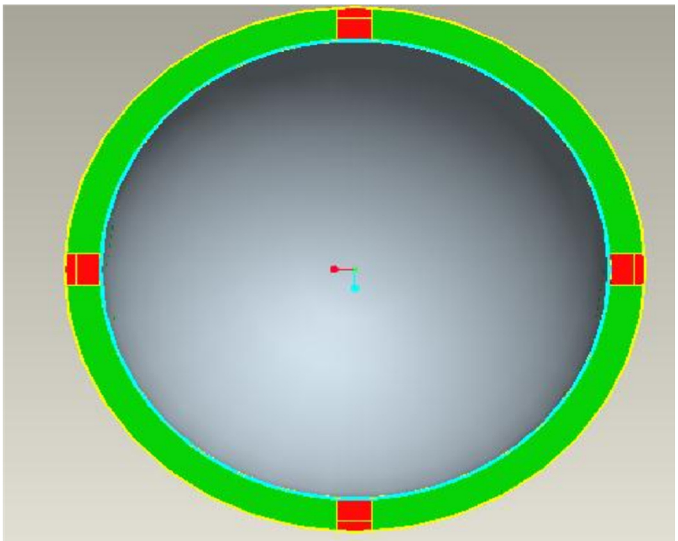

Figure 2 Cut section of the Cryogenic Tank

The inner vessel is a cylindrical container with two semispherical heads, one on the top and another on the bottom of the cylinder. The inner vessel is in direct contact with the liquid methane at -161.6 ºC. The material used for the construction of the inner vessel has to fulfill the requirements of cryogenic temperatures and high pressure to ensure safety. The steel alloy selected for the inner vessel needs a high content of Nickel and so the chosen alloy is the ASTM A553 containing 9 % Nickel. The outer vessel is in direct contact with the insulation, and the other side, with the environment. The material chosen for this vessel is the AISI 1040 steel. The inner and outer vessels are separated by number of small rectangular blocks called supporting blocks. The material used for supporting blocks need to resist high loads coming from the mass of liquefied gas and mass of the inner tank and also it must and low density. Polyamide is the material used for supporting block because it should withstand high strength and low thermal conductivity. The cavity between both vessels is filled with glass bubbles. The aim of the insulation is to minimize the amount of heat that the liquid inside the inner vessel exchanges through the walls, because of the difference in temperature with the environment outside the vessel. For this purpose the empty space between both vessels is completely filled with this material.

3. BOIL-OFF IN LNG

Boil-Off Gas (BOG) is the vapour phase in the LNG tanks. BOG can be a major problem for LNG storage tanks. If the BOG increases it will leads to an increase in the pressure of the LNG tank. Because the volume of the gas form is much higher than the liquid form. As tanks cannot have perfect insulation, LNG storage vessel can absorbs heat continuously due to the huge temperature difference between the liquid and the outside atmosphere. Due to this the temperature and pressure inside the tank is increased and BOG also increase.

4. THERMAL CONDUCTANCE OF MATERIALS AT CRYOGENIC CONDITION

In components like supports, clamps, collars the heat is transferred mainly by conduction. The heat conduction appears between two heat sources with different temperatures. In cryogenic tank, the temperature difference between inner and outer vessel may reach the level of 200 degree Celsius or even more, under such conditions. Heat properties of materials as steels or plastics can be variable, usually as the function of temperature. Dependence between the heat conduction and temperature for steel is presented in fig. 2. Change of temperature from plus 20

Celsius degrees down to minus 220 Celsius degrees causes reduction of heat conduction coefficient by approximately 25%. This effect is very advantageous, but still value of the heat conduction coefficient remains high.

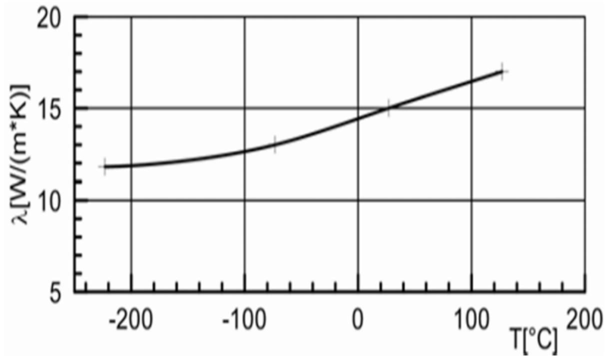

Figure 3 Heat Conductivity of Steel in Function of the Temperature

Decreasing of temperature from plus 20 Celsius degrees down to minus 200 Celsius degrees caused lowering of heat conduction coefficient approximately five times in polyamides. Therefore, the effect is very advantageous for the sake of the support blocks heat insulation properties.

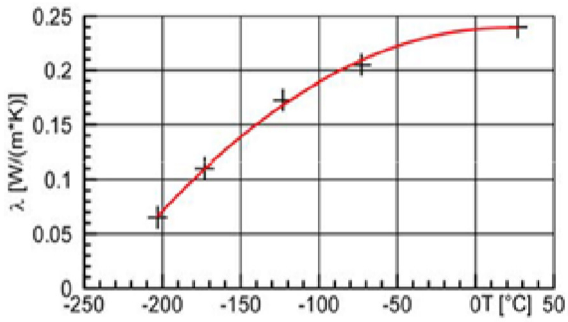

Figure 4 Heat Conductivity of Polyamide in Function of the Temperature

The heat conduction coefficient has been approximated using the second order polynomial. The result is presented in formula. $\lambda(T) = -0.0503 + 0.0020T - 3.4753T^2$ (1)

5. HEAT LEAK INTO THE STORAGE TANK

The heat from the atmosphere leak into tank causes LNG vaporization process. The heat leakages can be determined on each side of the tank. The thermal resistance of the inner and outer vessell can be determined from [6].

$= 1/(1/R_m + 1/R_s)$ (2)

Where R_m thermal resistance of the multilayer insulation,

$R_m = \Delta t / K_m.S$ [7], Rs thermal resistance of the supporting block material.

$R_s = \Delta t / K_s.S_s$ [7],

S is the inner shell area of the tank, $S_s$is the support junction area, Δt is the multilayer insulation thickness, K_m is the thermal conductivity of insulation, and K_s is the thermal conductivity of stainless steel. The heat flow rate across the shell of

LNG tank is estimated as $q = \Delta T/R = \Delta T\ \{Km.S / \Delta t + Ks.Ss / \Delta t\} = \Delta T\ \{(K_m.S + K_s.S_s) / \Delta t\} = \Delta T\ \{(Km.\ \beta .V + Ks.\ \alpha.\ S\ s)/ \Delta t$ (3)

Where $\alpha = S_S/S$, the ratio of the support block area and total area, the area density of tank $\beta = S/V$, and V is the volume of LNG tank. The temperature difference between the atmospheric and the LNG is $\Delta T = T_\infty - T$, where T_∞ is the atmospheric temperature. For a plain tube the area density is $\beta = 4/D$, where D is the diameter of the tube. From Eq. (2) the heat conductance of the tank shell is;

$$C= \{(K_m + \alpha .K_s).\ \beta.V\}/ \Delta t \qquad (4)$$

6. ASSUMPTION OF THE MODEL

The assumptions can be made in the analysis are discussed below. These are helps to simplify the research work. The LNG used in this analysis has a composition of 100% of methane but in actual practice the composition of LNG is nearly 90%. In the design of LNG storage vessel this assumption is reasonable because high percentage of methane content favorable for more BOG generated. The temperature of LNG in the inner vessel is maintained close to boiling temperature (-165°C) and the outside temperature of the outer vessel is assumed to be equal to atmospheric temperature (25°C) and the temperature distribution depends on the thermal conductivity of material selected for inner and outer vessels, supporting block and insulating material. The operating pressure of the tank is equal to standard atmospheric pressure (1 bar).

7. SIMULATION RESUTS

The FEM model was created in order to determine the temperature distribution in the area of support block. The boundary conditions are constant temperature at inner wall of inner tank and outer wall of outer tank.

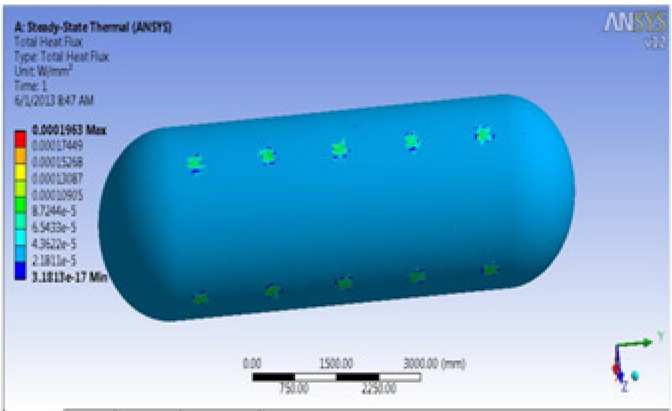

Figure 5 Total Heat Flux Generated

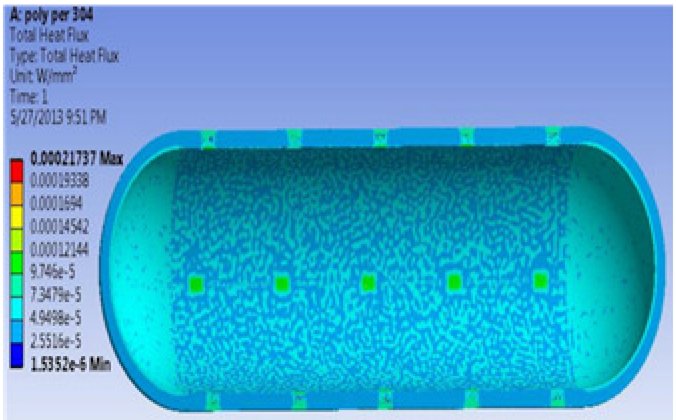

Figure 6 Total Heat Flux Generated

Figure 7 Magnified View of Temperature Distribution in the Tank

8. BOIL OFF RATE

In this paper the boil off rate [BOR] was defined as what percentage of LNG to be boiled off in order to maintain the LNG at the boiling temperature in the LNG tank. The typical value of BOR are depending on insulation properties and support material property. The amount of BOG can be estimated from many available heat transfer textbooks and studies done by researchers by applying energy balance and assuming steady flow of heat leakage through the LNG tank shell. So that the amount of BOR can be estimated as

$$BOR = (q/\rho\ V\ h_{fg}) \times 24 \times 3600 \times 100\% \quad (5)$$

Where q is total heat leakage through the tank shell (J/sec),h_{fg} Latent heat of vapourisation (J/kg) evaluated at normal boiling temperature, and atmospheric pressure (1 bar), ρ and V is the density and volume of the LNG inside the tank valued 424 kg/m^3 and 28.4m^3 respectively.

9. CONCLUSION

In this work was undertaken the problem of transporting and storing liquefied Natural gases, in a multi-walled high-pressure tanks. One of the most important task of this type of tanks is design of inner support blocks. The blocks should have as low heat conduction coefficient and less weight as possible. In this work polyamide has been proposed as a material for supporting blocks. The main reasons of using the polyamide as supporting material were: it has good strength properties, have low heat conduction coefficient, easy to form adequate geometrical shape and low costs. Proposed geometrical solution of the support block, close to rectangular prism is characterized by low area of heat exchange and simplicity of production. The BOR is computed in this paper 28.4 m^3 road transport tank with ambient temperature of 30° C. The BOG computed in this paper for 28.67m^3tank with ambient temperature 30° C is 0.0372 kg/kg per day.

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