IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 15, Issue 5 Ver. II (Sep. - Oct. 2018), PP 07-11
www.iosrjournals.org

Simulation analysis of static lossless storage for LNG vehicle storage tank

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Abstract : *Analyze the variation curves of temperature and pressure in the storage tank during the static lossless storage of LNG vehicle . Calculate the daily heat leakage and the static evaporation rate of the storage tank are calculated. Based on lumped parameter method, the static process of the tank is modeled and calculated by using the simulation software Sinda/Fluint, and the variation of pressure in the tank under different initial filling rates is studied. The results show that the smaller the initial filling rate is, the faster the pressure in the tank rises and the shorter the safe storage time is.*
Keywords - *Liquefied natural gas; static storage; dynamic simulation; Sinda / Fluint*

Date of Submission: 08-09-2018 Date of acceptance: 25-09-2018

I. Introduction

With the development of economy and the acceleration of urban process, the world energy crisis and environmental pollution are becoming more and more serious. New energy has been highly favored by people. Liquefied natural gas (LNG) is recognized as a green energy in the world and applied in many fields, especially in the automobile industry. Storage tank is a kind of high vacuum adiabatic container for storing LNG. It is the core equipment of LNG automobile supply system. When the vehicle is stopped, the gas supply system of LNG vehicle is in non-working state, that is, static lossless storage state. During static lossless storage, environmental heat leakage leads to the continuous vaporization of low temperature liquid in the tank, which increases the pressure and temperature in the tank, and causes medium overpressure discharge, which brings about a series of safety problems. Therefore, the study of static evaporation rate of cryogenic vessels is of great significance in ensuring the safe operation of LNG vehicles, improving the performance of on-board LNG tanks and prolonging the storage and transportation time of LNG. Zhou man analyzed the factors affecting evaporation rate, and concluded that the evaporation rate of cryogenic vessels increases with the increase of filling rate, and the evaporation rate increases with the increase of temperature [1-3]

II. Establishment Of Static Lossless Storage Model

2.1 Selection of research objects

The United States is the world's fastest growing LNG automotive technology, it has more than half of the world's LNG filling stations and LNG vehicles.Terrawatton is the world's largest multinational manufacturer specializing in research and development of gas control equipment. The company produces complete specifications for LNG storage tanks with long storage life and easy to use.According to the specification parameters of LNG tank of Terrawatton Company, as shown in Table 1, the tank of LNG-119V is selected as the research object.

Table 1 Specification parameters of LNG Storage Tank of Terrawatton Company

Model	LNG-72V	LNG-90V	LNG-119V	LNG-150V
Nominal capacity /L	270	340	450	570
External diameter /mm	660	660	660	660
Contour length /mm	1320	1555	1930	2346
Empty mass/Kg	177	202	241	284
Main relief valve discharge pressure/MPa	1.59	1.59	1.59	1.59
Secondary relief valve discharge pressure/MPa	2.07	2.07	2.07	2.07

Select the LNG-119V tank, as shown in Table 2:

Table 2 LNG-119V Main technical parameters of storage tank

Project	Unit	Inner tank	Hull	Remarks
Main relief valve discharge Pressure/MPa	MPa	1.59	-0.1	Outer pressure
Secondary relief valve discharge pressure/MPa	MPa	2.07	-	
Nominal capacity	L	450	-	
Filling rate	-	0.9	-	
Tank size	mm	≈610×1830	≈660×1930	Diameter × length
Main material	-	06Cr19Ni10	06Cr19Ni10	
Minimum thickness of cylinder	mm	3.34	3.6	
Minimum head thickness	mm	3.01	3.41	
Net weight	kg	≈283		

Filling quality	kg	≈174	
Adiabatic form	-	Vacuum multi-layer insulation	
Apparent thermal conductivity	W·m-1·K-1	1.73×10-5	

2.2 Establishment of models

The heat leakage in the tank is composed of three parts: cylinder heat leakage, neck tube heat leakage and bottom support heat leakage.

According to the heat leakage of the above three parts, the static lossless model of LNG storage tank is established. Firstly, the following assumptions are made to the model:

(1) The ambient temperature and pressure of the tank remain unchanged at 293K and 1. 03×10^5 Pa.
(2) The tank is divided into two parts: gas phase and liquid phase. Accordingly, the metal wall and adiabatic layer of the tank are divided into two parts, which are in contact with the gas phase and the liquid phase, respectively.
(3) The initial filling rate of the tank is 90%.
(4) The storage tank stays for one week.

A static lossless storage model for storage tanks is established as shown in figure 1:

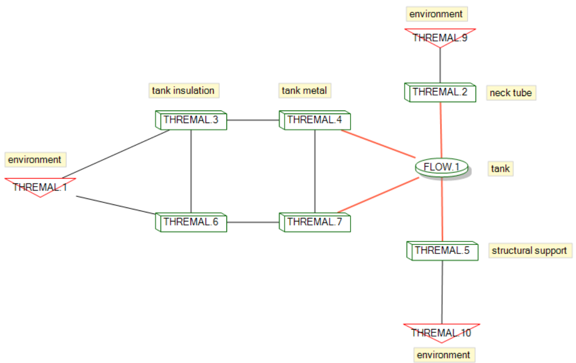

Fig 1 Static lossless storage model

THERMAL1,THERMAL9 and THERMAL10 represent the external environment, the temperature and pressure remain at 293K and 1.03×10^{5} Pa. THERMAL4 and THERMAL7 represent the metal layer of the storage tank. The gas phase and liquid phase contact with the storage tank .THERMAL3 and THERMAL6 represent the adiabatic layer of the storage tank. FLOW1 represents storage tank, initial temperature is 111.15K, initial pressure is 1.3×10^5Pa. the filling rate is 90%. THERMAL2 represents the neck tube, THERMAL5 represents the bottom support structure. THERMAL4 and THERMAL7 are connected to the gas and liquid phases of the FLOW1 through the "TIE" element, respectively, for energy transfer.

Calculation of convection heat transfer coefficient between gas phase and liquid phase of metal layer and natural gas in tank by natural convection heat transfer formula near vertical plate [4]

$$Nu = \left\{ 0.825 + \frac{0.387 Ra^{\frac{1}{6}}}{\left[1 + (0.492/pr)^{\frac{9}{16}} \right]^{\frac{8}{27}}} \right\}^2 \quad \text{..................(1)}$$

$$Nu = hL/\lambda \quad \text{..(2)}$$

$$Gr = \frac{g\beta_t \Delta t L^3}{\upsilon^2} \quad \text{...(3)}$$

g is gravity acceleration,β is coefficient of expansion,L is characteristic dimensions of the system,v is kinematic viscosity.

According to the known conditions in Table 1, the height of the tank is 1930mm, the fluid temperature in the tank is 111.15K.According to the above formula, the convection heat transfer coefficient between the metal layer and the liquid phase of the tank is 429.37W·m^{-2}K^{-1}, and the convection heat transfer coefficient between the metal layer and the gas phase of the tank is 8.6W·m^{-2}K^{-1}.

III. SIMULATION ANALYSIS

3.1 Static analysis of storage tank

The open pressure of the tank relief valve is 1.59 MPA. The pressure, temperature and volume change curves of the tank are obtained by simulation after a week of statics, as shown in figure 2, 3 and 4:

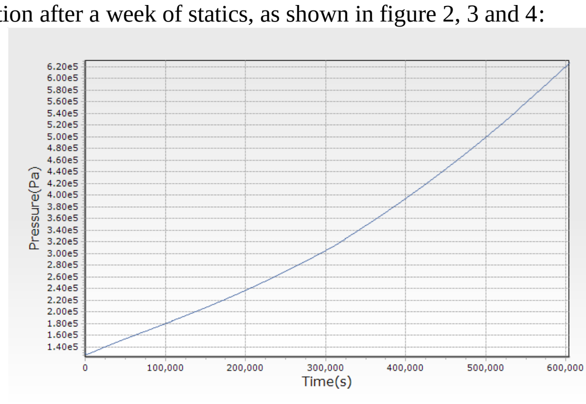

Fig. 2 Pressure rise curve in tank

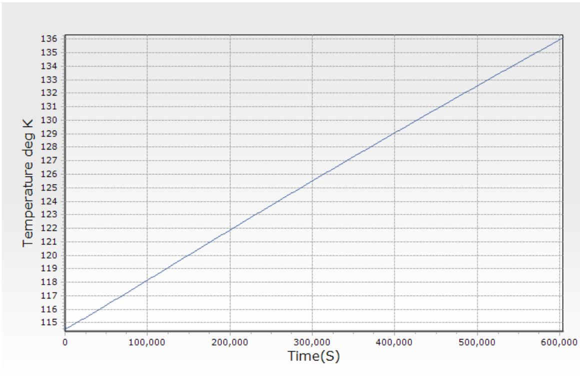

Fig. 3 Temperature rise curve in tank

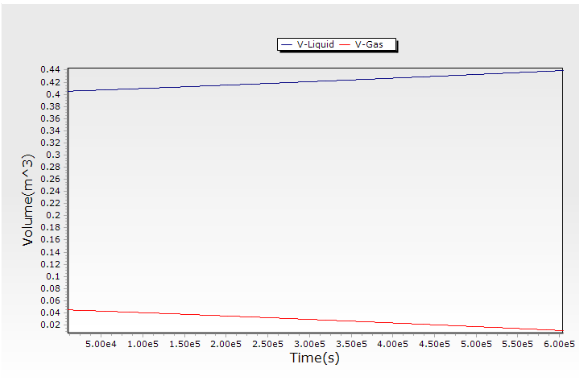

Fig. 4 Change curve of gas-liquid volume in tank

According to the simulation results, it can be seen that the pressure in the tank is within the range of the safety valve pressure and the storage tank is in a safe state after a week of statics.

It can be seen from figure 2 that under the same initial filling rate, the pressure in the tank increases more and more rapidly with the increase of storage time. This is because as the external heat continues to leak in, the temperature of the tank increases gradually, the latent heat of vaporization of the liquid decreases, and the same heat causes more liquid to vaporize, so the pressure rises faster.

Figure 3 shows that the temperature in the tank increases as the storage time increases.

Figure 4 is the volume change curve of gas and liquid in the tank. It can be seen from the diagram that the volume of liquid in the tank keeps rising, indicating that the volume expansion velocity of the liquid in the tank is greater than the vaporization velocity of the liquid.

3.2 Analysis of daily leakage heat and static evaporation rate

Static evaporation rate is an important index to reflect the adiabatic performance of gas cylinders.It means a tank at rated filling rate,the percentage of cryogenic liquid mass lost by natural evaporation within 24 hours after heat balance and cryogenic liquid mass at effective volume of vessel.Converted to evaporation rate in standard environment (20 ℃ 0.1 MPA) .

The initial filling rate of the tank is 0.9. According to the simulation results, the daily heat leakage of the tank is 14.26W. the result is shown in figure 5.

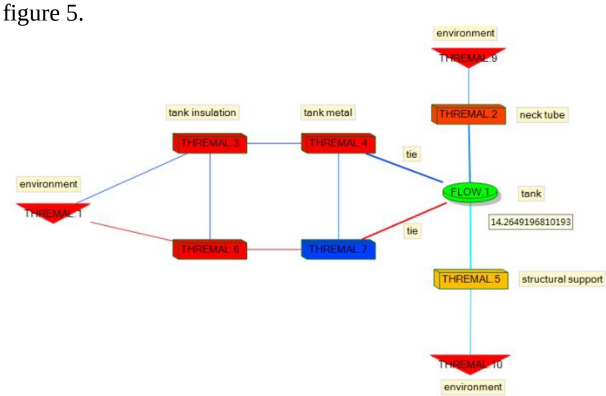

Fig. 5 Daily heat leakage from storage tanks

According to the heat leakage, the static evaporation rate can be calculated as follows:

$$\alpha_{LNG} = \frac{86.4 \times Q}{r \times \rho \times V} \times 100\% \text{.......................................}(4)$$

Q--Diurnal heat leakage，W

P--Density of cryogenic liquids，kg/m^3

V--Effective volume of container，m^3

r--Latent heat of vaporization of cryogenic liquids，kJ/kg

According to the calculation, the static evaporation rate of the tank is 1.422%

3.3 Simulation Analysis of different filling rates

According to the heat transfer path, the heat leakage is transferred from the tank to the cryogenic liquid. In the gas phase area above the liquid level, the heat resistance from the inner tank to the liquid is larger than the heat transfer from the liquid below the liquid level to the liquid. Therefore, the full rate will affect the evaporation rate. For different materials, different structures and different adiabatic forms, the effect of the change of filling rate on evaporation rate is different.For the effect of filling rate, Xie Gaofeng and Wang Rongshun measured that when the filling rate of cryogenic vessel increased from 24.7% to 75%, the corresponding daily evaporation rate increased by 17.3%, but there was no general conclusion [5].Nie Zhongshan and Li Qing think that the evaporation rate of cryogenic vessel is related to the filling rate of the vessel. The basic change trend of evaporation rate is that the evaporation rate decreases with the decrease of the filling rate, and the evaporation rate basically keeps constant when the full rate is less than 50% [6].Bi Longsheng and others think that evaporation rate varies with the filling rate of three types of curves, that is, flat type, descending type and rising type [7]. Chen Guobang and Zhang Peng believe that the loss of liquid evaporation decreases rapidly with the decrease of liquid level when the inner packagings are made of stainless steel, while the loss of evaporation of containers made of aluminum alloy is almost unchanged [8].

The pressure variation curves of tanks under different filling ratios are analyzed by Sindafluint.

The initial filling rate of the tank is 0.9, 0.7, 0.5 and 0.3 . According to the simulation results, the pressure variation curves of the tank under different initial filling rates are obtained as shown in Fig 6.

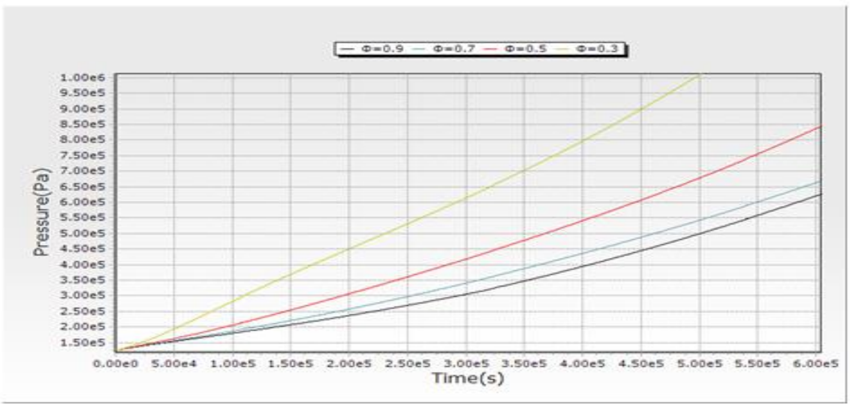

Fig. 6 pressure rise curve under different initial filling rates

It can be seen from figure 6 that the smaller the initial filling rate, the faster the pressure in the tank rises and the shorter the safe storage time is. This is because the internal energy of the liquid is much greater than the internal energy of the gas. After absorbing the same amount of heat, the lower the liquid content, the more liquid vaporized and the faster the pressure rise.

IV. CONCLUSION.

Based on lumped parameter method, the simulation software Sinda/Fluint is used to model and analyze the static lossless storage process of LNG vehicle. The following conclusions are obtained:

(1) At the same initial filling rate, the pressure increases faster and faster with the increase of storage time. This is because as the external heat continues to leak in, the temperature of the tank increases gradually, the latent heat of vaporization of the liquid decreases, and the same heat causes more liquid to vaporize, so the pressure rises faster.

(2) The liquid volume in the tank is increasing, which indicates that the volume expansion rate of the liquid in the tank is higher than the vaporization rate of the liquid.

(3) The smaller the initial filling rate, the faster the pressure rise and the shorter the safe storage time.

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Ping Fang “Simulation analysis of static lossless storage for LNG vehicle storage tank.” IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) , vol. 15, no. 5, 2018, pp. 07-11