**International Journal of Engineering and Advanced Research Technology (IJEART)**
**Volume-1, Issue-1, July 2015**

# Thermal-mechanical Coupled Analysis of the Inner Tank of Large-scale LNG Storage Tank

**Lan Zhang, Xue Yang**

*Abstract*—**With the development of LNG industry and the change of energy structure, large LNG storage tanks are used widely when the requirements of transportation and environmental protection are considered. So, how to ensure the safety of storage tank is very important. Mechanical properties of the inner tank of large-scale LNG storage tank directly affect the reliability of the whole tank because of it contacts with the liquid directly. Based on the finite element method, the finite element model of the inner tank was built, and its stress was analysed. The results show that the stress in the state that has no thermal coupling significantly lower than it in the state that has thermal coupling, so the temperature load is the main load of the inner tank. The stress of inner tank is controlled by the thermal expansion coefficient of material. The maximum stress of tank linearly increases with the increasing of thermal expansion coefficient and wall thickness. Those results can provide a reference for the overall design of large-scale LNG storage tank and the failure analysis.**

*Index Terms*—**LNG storage tank, thermal-mechanical coupled, finite element, thermal stress**

## I. INTRODUCTION

Liquefied natural gas (LNG) industry is in a rapid development period now, and LNG has become a sort of energy which has the fastest trade growth in the world[1]. LNG can supplement the shortage of the petroleum resources, ensure diverse energy supply and improve the environmental quality by increasing the use of LNG. LNG as a sort of more efficient and clean energy than petroleum, its demand continues to increase rapidly, and the inhomogeneity of the energy distribution makes the trade more frequently. Both the use and the trade of LNG cannot leave the corresponding storage and transportation equipment. As the equipment to store and transport LNG, LNG storage tank belongs to the low temperature pressure vessel. The advantages of the storage and transportation of LNG are small volume, convenience and high safety performance, when it is compared with the storage and transportation form of pipeline and compressed natural gas. The advantages of large-scale storage tank are less steel, less land, small investment and easy operation management[2]. Therefore, LNG storage tanks, especially large-scale storage tanks, play an important role in the LNG industry, and the study of large-scale storage tanks will be beneficial to the steady and fast development of LNG industry. The property low temperature of LNG puts forward higher requirements on the material of storage tank and heat preservation. As a kind of efficient energy, LNG once leakage or explosion will cause immeasurable loss, so the structure design and the safety protection of tank must have strict requirements to ensure the safety of its storage and use.

**Lan Zhang, Xue Yang,** School of Mechatronic Engineering, Southwest Petroleum University, Chengdu, 610500

Due to the particularity of working condition of LNG storage tanks, the analysis of the affecting factors of its stress is an important content to guarantee safety design. The stress distribution of inner tank will directly determine the safety of the tank, because the inner tank direct contact with the liquid. This paper set up the thermal-mechanical coupled model of inner tank, and studied the influence rules that how the thermal expansion coefficient of material, temperature and the thickness of wall act on the thermal stress of inner tank.

## II. PROPERTY OF LNG

The main composition of LNG is methane[3]. Natural gas is gas under the atmospheric pressure, when the temperature downgrades to -162℃, it will take place liquidation and become liquefied natural gas.

The main properties of LNG are:

(1) Its temperature is low and it has a larger expansion ratio between gas and liquid. It will release more calories when burning, and it can be more convenient to store and transport it. At present, the transportation of LNG can be realized by the transport ship of LNG on the far and edge of the ocean area[4].

(2) The LNG has high calorific value, it can probably release about the quantity of heat of 9300kcal when burning $1m^3$ of natural gas combustion, this number is 1.7 times of 1t of the standard coal. And LNG can produce $1350m^3$ of gas per ton, which can generate electricity about 8300 kw·h.

(3) The sulfur content of LNG is very low, the emissions of sulfur dioxide only 1/6 of the coal when generate the same heat, and other harmful gas emissions should also be a lot less than coal and oil. Therefore, LNG has great value in environmental protection[5].

(4) When it is used as chemical raw materials, LNG can synthesis ammonia, methanol and olefin products more convenient in the directly or indirectly ways.

## III. NUMERICAL CALCULATION MODEL

LNG storage tank has a variety of forms, Figure 1 shows the more common type of storage tank on the ground. How to choose the form of storage tanks depends on a variety of factors such as the location of the LNG receiving station, surrounding environment, the safety factor, soil settlement, earthquakes and construction cost [6].

The storage capacity of large-scale LNG storage tanks[2] are 160000m3, as shown in Figure 2, the inner tank model was established, the height is 33m, the diameter is 80m, the thickness is 26mm. To improve the efficiency of solving, the model was generated by hexahedral grid, as shown in Figure 3.

Figure 1 LNG storage

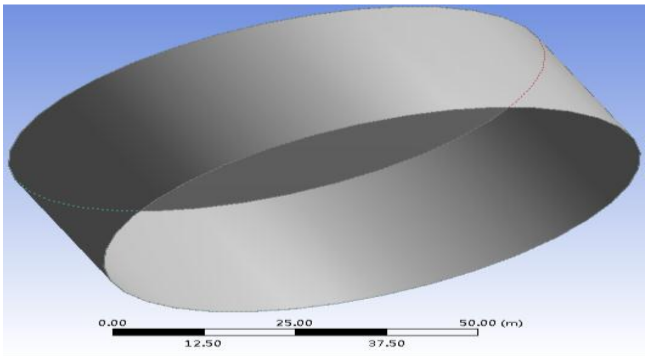



Figure 2 Geometric model of inner tank

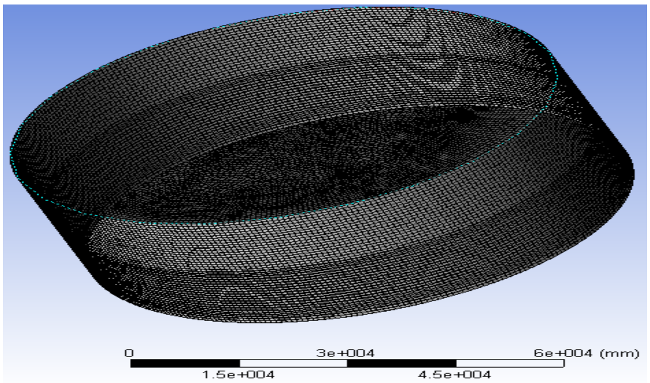
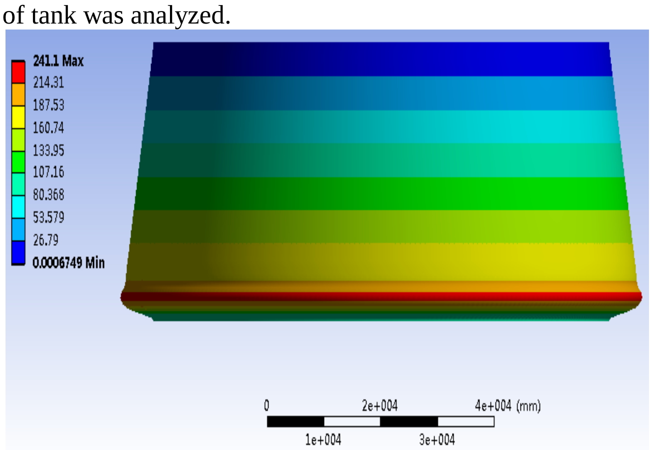



Figure 3 Finite element model

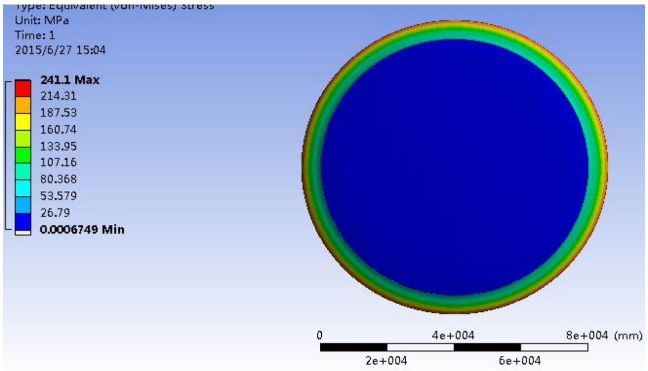
## IV. SIMULATION RESULTS

### *4.1 No thermal mechanical coupling*

The hydraulic load was applied in the inner wall of tank, and the bottom of tank was fixed. Then the stress distribution of tank was analyzed.




**a. Stress distribution of the external surface**




**b. Stress distribution of the bottom**

**Figure 4 Stress distribution of the tank**

As shown in Figure 4, the high stress area is mainly focused on a certain range around the bottom; stress decreases stably to almost no stress state from the high stress area along the lower height up; stress decreases sharply to a certain stress value from the high stress area along the height down; and stress distribution is uniform along the thickness.

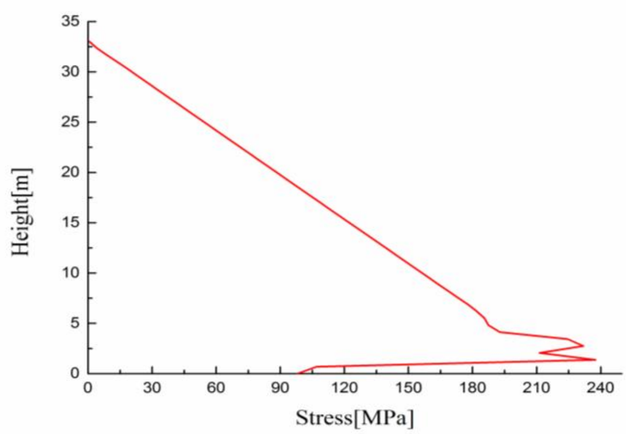


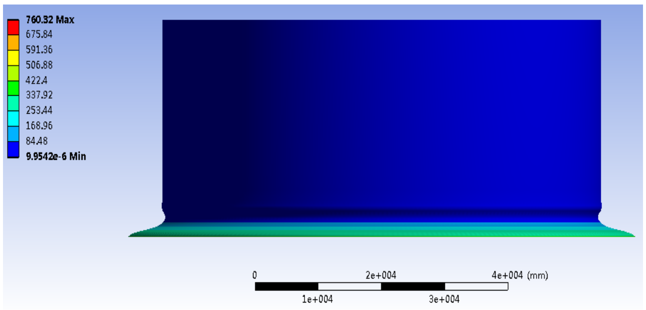

**Figure 5 Stress change curve along the height**

A vertical straight line was got, which along the height direction, its stress distribution as shown in Figure 5. The relationship between stress and height is approximate linear decrease when the height within the scope of m~33m. The stress increases with height decreases when the height within the scope of 4~5m, and the rate of change becomes larger. The stress decreases with height decreases when the height within the scope of 3m ~ 4m, and the rate of change becomes larger. The stress increases with height decreases when the height within the scope of 2~3m, and the rate of change becomes larger. The stress sharply decreases with height decreases when the height within the scope of 0~2m, and the stress finally steady at around 100MPa. The stress is larger when the height within the scope of 1~4m in the figure.

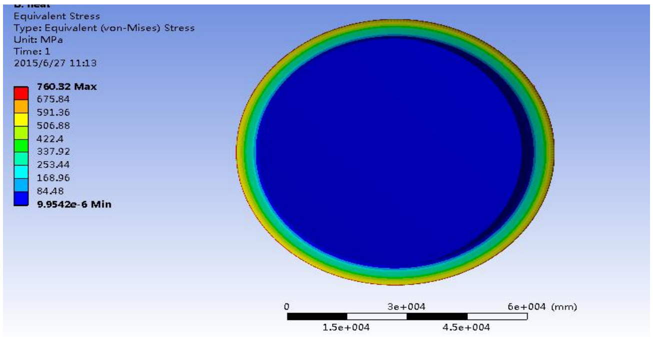
### *4.2 Thermal mechanical coupling*

*(1) No medium*

Only the temperature load and hydraulic load are considered, because the model is simplified and gravity is relatively small. The inner wall temperature is -165℃, and the other wall is adiabatic for the insulation measure of tank, the bottom of model is fixed.




a. **Thermal stress distribution of the external surface**




b. **Thermal stress distribution of the bottom**

**Figure 6 Thermal stress distribution with no medium**

As shown in Figure 6, the thermal stress mainly concentrated in the around of tank bottom, and it rapidly decreases with height increases, the tank almost has no stress when height is far from bottom, which conform to the Saint Venant Principle. The maximum stress is on the inner wall of bottom plane, and stress increases from external wall to inner wall in the same plane, so the stress of inner wall is the largest.

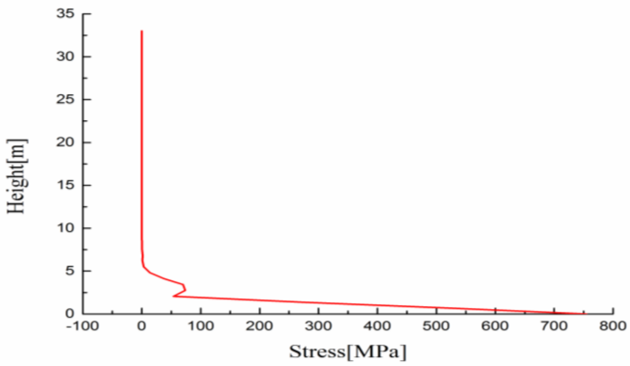
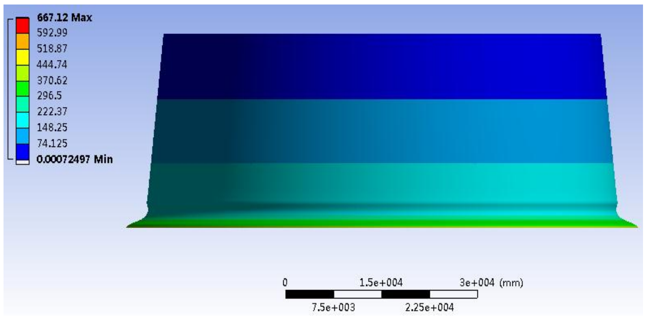



**Figure 7 Thermal stress change along the height with no medium**

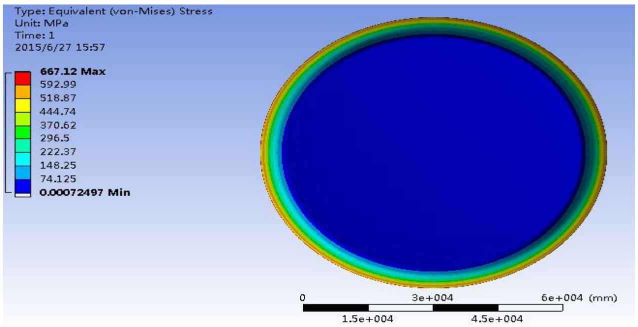
Figure 7 shows the change of the stress of tank which along the height direction. When the height is more than 5m, the tank almost has no stress. The stress increases with height decreases when the height within the scope of 3m ~ 5m. The stress decreases with height decreases when the height within the scope of 2m ~ 3m. When the height is less than 2m, the stress sharply increases with height decreases, and it reach to the maximum value in the bottom. Therefore, the stress is larger when the height within the scope of 0~ 2m, so some appropriate measures to strengthen the structure can be applied in this place.

（2）Under the action of hydraulic load

The temperature load and hydraulic load are analyzed in the same time, and a vertical straight line was got to analyze stress distribution, which along the height direction. The main factors can be determined according to how the loads influence the whole stress distribution.




a. **Stress distribution of the external surface**




b. **Stress distribution of the bottom**

**Figure 8 Thermal stress distribution of the inner tank**

Figure 8 shows that the high stress area is located around in the tank bottom and its stress distribution is similar to the thermal stress distribution, so the high stress area is determined by temperature load. Low stress area is located in the middle and top of tank, and its stress distribution is similar to the hydraulic stress distribution, so the high stress area is determined by hydraulic load. According to the design requirements of tank, structure strength depends on the stress distribution of high stress area, and the stress level of temperature load is significantly higher than that of hydraulic load, so the temperature load is the main load of tank. Because of the hydraulic load, the total stress level is smaller than the thermal stress level in the high stress area and the maximum of total stress is also smaller than that of thermal stress, so the hydraulic load is a beneficial load.

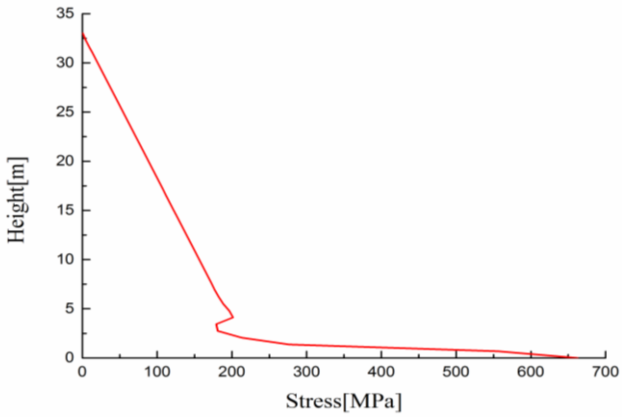



**Figure 9 Thermal stress change along the height**

The relationship between stress and height is approximate linear decrease when the height within the scope of 4m ~ 33m in the Figure 9, which similar to the hydraulic stress distribution. The stress decreases with height decreases when the height within the scope of 3m ~ 4m. When the height is less than 3m, the stress sharply increases with height decreases, and it reach to the maximum value in the bottom, which similar to the thermal stress distribution. Therefore, the stress is larger when the height within the scope of 0~ 3m.

## V. ANALYSIS OF SENSITIVITY PARAMETERS

### *5.1 Effect of thermal expansion coefficient*

According to the results of the coupling analysis, the temperature load is the main load of tank, and it is the result of the thermal expansion coefficient of material and structural constraints. The thermal expansion coefficient of material is change within the scope of $9 \times 10^{-6}$~$1.7 \times 10^{-5}$℃$^{-1}$when structure is unchanged, the thermal stress distribution and the total stress distribution are analyzed to get the change trend of maximum stress.

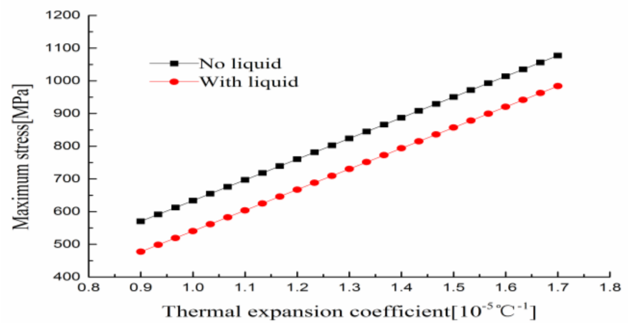



**Figure 10 Relationship between the maximum stress and thermal expansion coefficient**

The relationship between stress and thermal expansion coefficient is approximate linear increase in the Figure 10, and the maximum total stress is smaller than the maximum thermal stress in the same thermal expansion coefficient, which further shows that temperature load is the main load and hydraulic load is beneficial load. Therefore, the low thermal expansion coefficient will be beneficial to ensure the structural strength in the material selection process.

### *5.2 Effect of wall thickness*

The thermal stress distribution and the total stress distribution are analyzed to get the change trend of maximum stress when the thickness within the scope of 10 ~ 100mm.

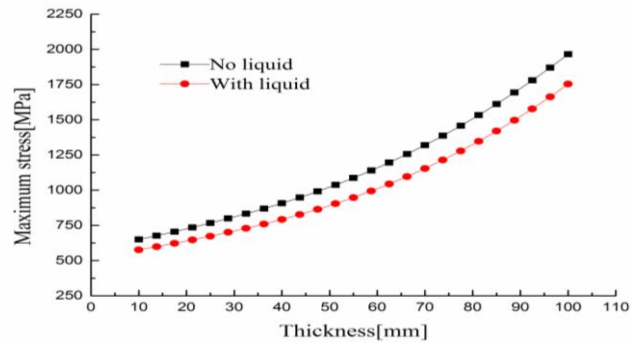



**Figure 11 Relationship between the maximum stress and wall thickness**

The maximum stress increases with the thickness increases in the Figure 11, and the rate of change becomes larger. The maximum total stress is smaller than the maximum thermal stress in the same thickness. Therefore, the thickness should be reduced as far as possible on the basis of meet other conditions.

### *5.3 Effect of temperature*

The thermal stress distribution and the total stress distribution are analyzed to get the change trend of maximum stress when the temperature within the scope of -190~ -140 ℃ .

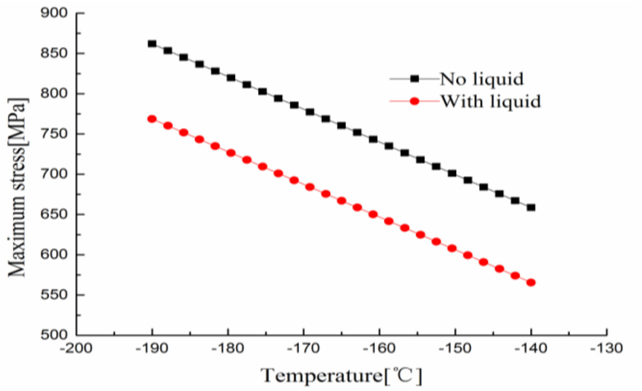



**Figure 12 Relationship between the maximum stress and the temperature**

The relationship between stress and temperature is approximate linear increase in Figure 12, and the maximum total stress is smaller than the maximum thermal stress in the same temperature. Therefore, the temperature should be higher on the basis of ensure the storage condition of LNG.

## VI. CONCLUSIONS

The conclusion about how the load and the structure influence the stress of tank is got by using the finite element method to analyze the inner tank of large-scale LNG storage tank. The stress distribution is mainly controlled by temperature load and high stress area is located within the scope of 0~3m, the hydraulic load as a beneficial load can reduce stress concentration. The relationship between stress and thermal expansion coefficient is approximate linear increase, and the small thermal expansion coefficient of material is helpful to reduce the structural stress. The maximum stress increases with the thickness increases, and it decreases with the temperature increases.


## ACKNOWLEDGMENT

This paper is supported by Science and Technology Innovation Talent Engineering Project of Sichuan Province （No.2015097）.


## REFERENCES


[1] Li Xukun. The Thermal Stress Analysis of A Large-scale LNG Storage Tank[D]. Harbin Engineering University,2013

[2] Wang Zhenliang. Research of the Design Theory and Method on Large LNG Cryogenic Storage Tank[D]. Xi'an Shiyou University,2011.

[3]Yan Guangcan,Wang Xiaoxia. Liquefied Natural Gas(LNG)Technology[J]. Natural Gas And Oil, 2005,23(2):10-16.

[4] Zhang Yong.Ocean Shipping of Liquefied Natural Gas(LNG)[J].Port＆Waterway Engineering,2004,362(3):65-67.

[5]Gao Chunmei,Li Qin,Shao Zhenyu. Liquefied Natural Gas Storage and Application Technology [J], Urban Gas,2002,324:18-22.

[6]Li Jianjun. Construction Technology of LNG Storage Tanks[J]. Welding Technology, 2006, 35 (4): 68-79.



**Lan Zhang**, Master graduate student in southwest petroleum university. The research direction is design and simulation of oil and gas equipment.

**Xue Yang**, Master graduate student in southwest petroleum university. The research direction is pipe mechanics.