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Efficient Design of a Large Storage Tank for Liquefied Natural Gas

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Abstract

Natural gas is known as a green source of energy due to high purity, high energy density and environment friendly. To transport natural gas, it is an important to convert it into liquid case to reduce the cost, therefore the design of storage tank can be important factor in the natural gas trade. Liquefied natural gas (LNG) tank as a kind of storage column is quite different with other storage columns. Firstly, the size of this type of LNG tank is highly large, which comes with capacity up to 200,000 m^3. LNG storage tank can be considered as a new technique in this field for many countries. Secondly, the low temperature of LNG will increase the isolation part and lead to difficult process through the operation and installation time. This work combines different designs codes to study in details the LNG tank design in terms of inner and outer construction, bottom design with corner protection, and top design with corner protection. In addition, the heat leakages have been calculated for each part to show that the heat leakage is acceptable.

Keywords: LNG; Storage tank; Mechanical design; Thermal design.

1. Introduction

The increasing demand for energy resources has made natural gas as an important source. Convert natural gas into liquefied natural gas reduces the volume by 600^{th} times and makes it suitable to transportation [1]. Since 2001, first production of liquefied natural gas (LNG) has been in China [1]. Features of LNG can be illustrated by inflammable and explosive which makes the transportation process safe. Therefore, the demand of austenitic stainless steel cryogenic vessel grew up very fast [1]. Many codes created to design a storage tank for these products with better features and effective design. Many storage tanks built around the world with high capacity such as Canvey Island tank constructed in 1960's with capacity 9000m³ [2]. Early in 1980's, the British Gas peak-built tank with capacity up to 50,000m³ [1]. Then, the construction of LNG storage tank developed with high capacities as shown in table (1).

Normally, the large size of storage tank increases the total price for the whole equipment. However, figure (1) shows that unit price decreases as total capacity increases. It is also interesting to know that the cost difference between single and full containment can be in the range of 17 % to 12 % as the tank capacity increases over the size range covered [1]. It might be the reason why the capacity of LNG tank keeps increasing in the whole world. The full containment tank should be the best choice for large size LNG tanks when considering the safety and operating conditions.

Jeon et al. (2003) illustrated the main parameters to design large capacity LNG storage tank with high efficiency in terms of construction cost and protection design [2]. Delome et al. (2005) used the smooth particle hydrodynamics (SPH) method to study the sloshing loads of LNG for a 140,000-kL in marine environment [3]. Attention should pay to main streams of LNG tank which can be illustrated by LNG input and output streams, condensed LNG input stream, BOG output stream, and discharge to the air stream as shown by figure (2). In addition, the LNG inner pump must be used at the bottom of inner tank to provide the motive power for LNG output stream, which can be used to transit between different tanks. The specification for this design can be shown in table (2). Heat leakages is another factor should be considered, where heat transfer is the main concept in this design. Abd and Naji studied design of heat exchanger in details to show that heat leakages can be considered as one of the main problem facing the industrial processes [4].

Based on the raw data, the tank will consist of 9 % nickel steel inner tank, pre-stressed concrete outer tank, suspended ceiling deck, secondary bottom and corner protection system, and bottom heating system. The design pressure is 29 kpag and design temperature is -170 oC. From HYSYS program, the design boil-off rate (BOR) used in the design is 0.025 % in volume per day. This study will clarify the full construction of high capacity LNG storage tank by integrate different codes in one design.

2. Design methodology

2.1 General methodology

As mentioned by Se-Jin et al. (2011), the need for revision of some codes provisions has been raised especially for the inner tank, in order to design an aboveground full containment LNG tank with a high capacity in an efficient and economical way [3]. The most commonly referenced codes for design of inner tanks were API 620 and BS 7777, which are different standards in America and European [5]. PR-EN 265002 provided a background for BS-EN 14620 that is the latest Euro code which reflected several important points required to design more reasonable dimensions for an inner tank with a high capacity [5]. The using of code API-620 or BS-EN 14620 is not enough to create an efficient design of LNG storage tank. Where, each code can give reasonable dimensions for each case and different types of tanks. For instance, BS-EN 14620 introduces full-containment as the better choice in the selection of the storage type. However, full-containment leads to some operations problems and environmental aspects in some cases. API-620 is perfect choice in aspects of material selection, where this code suggested suitable materials can reduce the capital cost of the tank [5].

As well as, both BS-EN 14620 and API-620 have limitations where these codes are focused on the metal fitting and metal construction. While, concrete structure considered widely. This work offers to combine all design codes by applying the preferred aspects for each code to create efficient design.

2.2 Material requirement

The design of LNG tank has a strict demand of material requirement, because of the low temperature and large capacity. The material selection will follow BS-EN-14620 code which recommends that all parts such as inner tank stairways and shell or bottom plate should use 9 % Ni steel, where the temperature at inner tank is up to -180^{o}C. While, the isolation part will include Polyurethane foam, resilient glass fiber, and perlite concrete to prevent heat leakages. For welding, the ASME/AWS SFA-5.11 or SFA-5.14 should be followed and Aluminum or 304 stainless steel can be used to the hanger at the top part.

3. Design of 9 % Ni inner tank

The inner part is the most important section which is in direct contact with LNG. The main body of inner tank design includes plate dimension, allowable stress and filling height with working volume up to 200,000 m^3. For isolation part, the design condition should cover BOR calculation results, annular space and insulation properties. The core part of design inner tank is static and dynamic calculations which cover shell thickness, annular plate, stiffener ring and tension, stress and force.

3.1 Process design of inner tank diameter

The diameter and height of the tank depend on the process design specifications. Table (3) shows a brief description of the total capacity of LNG tank with diameter and height dimensions [5]. Therefore, the design of 200,000 m^3 LNG storage tank will come with 85 m diameter and 37 m height and 84 meters from the inner tank.

3.2 Design height of inner tank and shell thickness

As chosen, the inside diameter of inner tank is $D_i = 84\ m = 84000\ mm$

And, the height of inner tank can be estimated to be around 37.6 m as shown below.

$$\text{Volume} = \frac{\pi}{4} D^2 \text{h}$$

$$200000\ \text{m}^3 = \frac{3.14 \times (84000)^2}{4} * h$$

Design liquid level: 36.22 m and maximum operating level: 35.92 m, now the liquid column static pressure can be calculated as below:

$$P = \rho g h$$

$$= 426 \frac{kg}{m^3} \times 9.81\ \frac{m}{s^2} \times 37.6\ m = 150\ kpa$$

The design pressure is 29 kpa as mentioned, then 150 kpa > 5% of 29 kpa, therefore it should be considered, and total pressure will be 29 + 150 = 179 kpa [6]. The shell thickness of inner tank can be determined by the following equation [7];

$$\delta = \frac{P_c \times D_i}{2 \times \sigma_k \theta - P_c}$$

$$= \frac{0.179 \times 84000}{2 \times 225 - 0.179} = 30\ mm$$

Then, the thickness of inner tank will be 32 mm.

3.3 Design of isolation thickness

The side wall isolation part is between inner tank shell and outer concentrated tank. In case of a leakage from inner tank, LNG may accumulate in the annular space between the inner and outer tanks and cool the wall/bottom corner. Perlite concrete, polyurethane foam and resilient glass fiber with 9 % nickel steel plates will be used to prevent heat losses [8].

The isolation thickness equation is given below;

$$\mathrm{D}_{out}\ln\frac{\mathrm{D}_{out}}{\mathrm{D}_{in}} = 2\frac{\lambda}{a_s}\times\frac{T_s - T_f}{T_a - T_s} = 2\times\frac{0.23}{8.141}\times\frac{30.7 + 273.15 - (-162 + 273.15)}{35.2 - 30.7} = 2.43$$

$D_{out} = 86.4\ m\ and\ thickness\ of\ isolation\ part\ is\ 1.2\ m.$

In this design, thickness of 1200 mm for side wall isolation used with 350 mm resilient glass fiber part (30 % of total isolation part) [8].

3.4 Mechanical design of the inner stiffness rings

Install stiffening ring in the storage tank can effectively resist the external extrusion and improve the stability inside of the tank when the tank is empty [7]. The usual procedure to design stiffening rings is by carrying the pressure load for a distance of 0.5 from space between the rings on each side of the ring. In this work, ten shell courses will be designed for inner tank and the specific data will be shown below.

$$Thickness\ of\ shell\ course(L_s) = \frac{inner\ tank\ height - thickness\ of\ ten\ plate}{10}$$

$$\mathrm{L_s} = \frac{37600 - 181.9}{10} = 3742.2\ \mathrm{mm}$$

In case, the number of stiffening rings is known, EN-14015 suggests below equation to find L_s.

$$K = \frac{95000}{5800P} = \frac{95000}{5800\times 2.5} = 6.55$$

$$L_s = \frac{K\times {e_{min}}^{2.5}}{D^{1.5}} = \frac{6.55\times 11^{2.5}}{84^{1.5}} \approx 3742.2mm\ \ [7]$$

As mentioned, the inner tank diameter is more than 40 m. Therefore, the minimum size of stiffening ring should be more than 200 mm as mentioned by Coulson, (1983) [9]. In this case,382 mm is chosen for all stiffening ring as shown in table (4).

Now, it is important to check if the support rings will act as effective stiffening rings. The design pressure is related to wind velocity pressure and vacuum degree which is between inner tank and isolation part.

$$\mathrm{Design\ pressure} = \mathrm{vacuum\ degree} + \mathrm{wind\ velocity\ pressure} = 25 + 0 = 25\ \mathrm{kpa}$$

Coulson (1983) shows that the critical pressure is related to Young’s modulus [8]:

$$P_C = K_c\times E\times(\frac{t}{D_o})^3 = 210\times 2\times 10^{11}\times(\frac{32}{84000})^3 = 23.22kpa < 29kpa$$

Hence, the critical pressure is below than the design pressure which means the stiffening rings are effective.

4. Design of Outer Tank

Traditionally, LNG storage tanks are built with significant amounts of 9 percent nickel steel or Carbon steel. However, this design will use concrete to reduce the material cost and time of construction.

4.1 Material and Basic Design Data of outer tank

There is no direct contact between the liquefied natural gas (LNG) and outer tank, where, the conditions are atmospheric conditions. The pre-stressed concrete can be used to achieve a better comprehensive performance with below specifications (table 5).

4.2 Mechanical design and Static calculation of outer tank

Jeon et al (2002) concluded that LNG pressure and inside pressure were the main design loadings of the wall, where LNG is assumed to be in contact with the outer wall for the case of leakage from the inner tank [2]. The most important thing is how to control the excessive moment and corresponding tensile stress at the lower part of wall that result from the restraint of wall deformation by the rigid bottom slab. Where, vertical stress σ can be calculated from below equation [2]:

$$\sigma = 6M / t^2$$

Normally, most of wall type of the above-ground LNG tanks, where the lower half of the height has varying thickness and remaining upper half constant thickness, which saying that three-tenth of the height for the material is saved in the present design [2]. Generally, the API-620 and EN-14620 did not mention the calculation of outer wall thickness and it is not possible to use the pressure vessel equation because it is for metal not concrete [9]. Hence, the thickness will be based on the design experience and after that recheck the pressure effects. The height of top wall is 4 times of bottom wall which are 31724 mm and 7931 mm respectively. The thickness of top wall is 700 mm and 1200 mm for the bottom wall. Same process uses for the inner tank to check the pressure effect of the wall. For the top wall, outer diameter at base of top of the outer concrete wall can be calculated by 700+700+86400=87800 mm. For the bottom wall, outer diameter at base of top of the outer concrete wall is 1200+ 1200+ 86400= 88800mm.

$$P_C(\text{top}) = K_c \times E \times (\frac{t}{D_o})^3 = 80 \times 10^5 mpa \times (\frac{700mm}{87800mm})^3 = 4.05mpa > 0.1mpa$$

$$P_C(\text{bottom}) = K_c \times E \times (\frac{t}{D_o})^3 = 80 \times 10^5 mpa \times (\frac{1200mm}{88800mm})^3 = 19mpa > 0.1mpa$$

The design pressure is under the pressure which outer tank of wall can bear with. It means the thickness of outer wall is effective.

5. Corner protection system at bottom and bottom design of tank

This section illustrates in detail the design of corner protection and bottom plate. Also, the heating system and bottom support which are inside and below of the concrete base slab are important for a design LNG tank.

5.1 Process design of corner protection systems for bottom part

In order to prevent the LNG from cracking of the lower concrete wall section, a liquid tight protection system thermally isolated with cellular glass insulation and shielded with 9 % nickel steel plates will be provided [9]. The design will be carried out using finite element analysis considering pressure loads and thermal stresses or movements.

The outer tank should be contained full inner tank contents. Minor and major leak cases must be checked by finite element analyses and combined with the maximum pressure in the analyses, which is already done in design of inner and outer tank. Table (6) shows some parts and the function of each one.

5.2 Mechanical design of bottom plate

The first level of the bottom tank is a 30 mm with 9% nickel steel annular plate, which is part of the inner tank as well [6]. Annular plate apparently not enough for the LNG tank, which means there are several parts should be designed to protect the tank at the bottom as shown in the table below with the location and thicknesses for each plate. Table (8) lists bottom plate parts with thicknesses.

5.3 Process design of bottom heating system

As mentioned, the temperature inside of inner tank is -162 ^oC, which can freeze the foundation and the wall. The embedded heating conduit should be set in the concrete base slab to prevent the cold liquid impact on the foundation [9]. Because of the bottom of inner tank is -162^oC constantly, and the environmental impact of the foundation is very small, we can assume the temperature in here is constant. Also, atmospheric convective and radiation can be ignored in this case, which means that it can choose the whole part from bottom of inner tank to concrete base slab as the research object and using the embedded heating conduit as the heating system to deal with low temperature. Because of the thermal resistance of steel pipe is very small, in this case, we only have to consider about the concrete and cellular glass.

5.3.1 Power of Heating System Calculation

The required heat energy at the bottom of the tank can be calculated as below:

$$Bottom\ \ area(A) = \frac{3.14 \times D^2}{4} = 6500.6m^2$$

The materials order with thicknesses as below:

Material	***Thickness*** *mm*	***Thermal Conductivity*** $(w/m.K)$
perlite concrete	*70*	$(0.09-0.22)$
cellular glass	*450*	0.056
concrete slab	*900*	0.79
Foundation with thickness 2000		

$$Average\ \ thermal\ \ conductivity = \frac{3.42m}{\frac{0.07}{0.1}+\frac{0.45}{0.056}+\frac{0.9}{0.79}+\frac{2}{0.79}}$$

$$= 0.276(\mathrm{w/m.K})$$

The top of concrete slab temperature is 273k with 283k for bottom part, the temperature of the bottom of inner tank is 110 k.

$$\mathrm{t} = -\frac{\varphi}{2\lambda}x^2 + \left(\frac{t_{w2}-t_{w3}}{\delta_{tot}}+\frac{\varphi\delta_{tot}}{2\lambda}\right)x + t_{w3} \qquad [9]$$

Then; the average heat intensity is 5.97 w/m^3. So, the power of heating system should be.

$$\mathrm{P} = \varphi\mathrm{V} = \frac{5.97\mathrm{w}}{\mathrm{m}^3} \times 6500.6 \times 3.42 = 132.7\ \ kw$$

5.3.2 Design of heating cable

Generally, Heat tracing cable is directly embedded in the concrete floor, embedment position from 50 ~ 100 mm to the top of concrete floor and below with wire mesh reinforcement [10]. In this case, we choose 100 mm as the distance between top of concrete base slab and embedded heating conduit. Overall, we have 300 circle embedded heating conduit with 50 mm diameter inside of concrete base slab.

5.4 Mechanical design of bottom support

LNG storage tank is heavy equipment therefore, the design of the concrete base slab considers as an important section to prevent sinking and collapsed of tank. There are more than 596 pipes under the concrete base slab which are separated in a circular area with 1.2 m of diameters and 25 m length per pipe. As mentioned by Hiroshi, N. et al (2012), the corrosion condition has been identified basic on the thickness measurement which is determined by ‘remote field testing’ and ‘actual pile investigation’ by excavating the upper portion of piles [6]. Based on the evaluation in this way indicated that there was no necessity of corrosion countermeasure for the next 50 years at least [6]. The measurement of thickness was carried out after removing extraneous matters such as corrosion products and residual material. Then the averages of pile thickness were calculated from measured thickness and weight for each 1 m. Observing the appearance of piles, corrosion is found on the outside surface evenly, where local corrosion of particular part is not found, nor rust inside of the steel pipe.

Therefore, the corrosion content is estimated from the outer wall of a pile by reducing the measured value from the initial thickness of a pile [6].

6. Top design of tank and top corner

6.1 Roof design

Many of above-ground LNG tanks with existing concrete roof domes have the relationship between radius of curvature and the diameter of outer wall. The ratio is normally 1/8, which is normally recommended for the roof domes [6].

In the design of LNG tank with 200,000 m^3 capacity, it is carefully considered to increase the rise of dome up to 0.8 from the outer wall diameter wall [11]. Except structural safety, there is no special code-related restriction imposed on the shape of concrete dome so far, however the codes for the carbon steel liner which is attached inside the concrete dome should be followed as an addition. API 650 specifies that radius of curvature of the liner should range from 0.8d to 1.2d [11].

Se-Jin et.al (2011) already represented the maximum hoop stresses of roof dome according to the membrane theory of shell structures under some major loading conditions. Consider about the safety factor and total stress, ‘G’ and ‘D’ are the best choice for design the roof. The shape of roof dome can give specific details about the roof. When choosing R=1.0d, a=30º, then the height about the top roof is 12192 mm.

$$H=R-\sqrt{3}/2\ R=91\ m-0.866\times 91\ m=12.192\ m$$

For the thickness of the roof, the following equation will be used (Ellipsoidal head).

$$t = (P_i \ x D_i)/(2SE - 0.2P_i\ ) \cong 600mm (with\ \ corrosion\ \ Allowance)$$

6.2 Top corner design with hanger, deck and isolation part

There are several different parts in this section are shown in table (8) [12].

These parts shown on the mechanical drawing below to check out the location and the function of each part.

7. Loadings

The following loadings shall be considered in the design of large, low-pressure storage tanks [12]:

The internal pressure as specified in API-620 and any partial vacuum resulting from operation. The weight of the tank and specified contents, from empty to full, with or without the maximum gas pressure specified. Superimposed loading, such as platforms and brackets for stairways and, where climatic conditions warrant, excessive snow. Wind loads, when specified, earthquake loadings and Loads resulting from connected piping [13].

7.1 Pressures

It is already considered about stress with inner tank shell, outer walls and top roof. However, 'Above Maximum Liquid Level' and 'Below Maximum Liquid Level' are still needing to be considered.

Base on the API-620, for the above maximum liquid level, the wails of the gas or vapor space should above the maximum liquid level which is located at the top of the tank [14]. It should be designed with a pressure more than pressure relief valve. In addition, it should be designed for the maximum partial vacuum which can be developed in the space when inflow of gas or vapor through the vacuum relief valves at maximum specified rate. During the hydrostatic test, the tank assumed to be filled to the top roof and the weight should be specified.

For the below maximum liquid level, API-620 mentioned that all portions of the tank at levels below the maximum liquid level should have each of their important elements designed for at least the most severe combination of gas pressure (or partial vacuum) and static liquid head affecting the element in any specified operating as the pressure in the gas or vapor space varies between the lowest and highest limits encountered during operation.

7.2 The weight of the tank and specified contents

Attention should be paid to several parts to calculate the overall weight of the tank such as inner tank weight, outer wall weight, fitting weight with platform, liquid loading and ladders, isolation part between inner tank and outer wall, the top roof weight and bottom concrete weight.

$$W_{total} = W_{inner} + W_{outer\ wall} + W_{isolation} + W_{fitting} + W_{top\ roof} + W_{bottom\ concrete}$$

Gavin, (2008) mentioned some values needed to calculate the total weight as below [14]:

1. The rough guide to the weight of fittings

Caged ladder, steel, 360 N/m length; Plain ladders, steel, 150N/m length; Platforms, steel, for vertical columns, 1.7KN/m^2 area; Contacting plates, steel, including typical liquid loading, 1.2 KN/m^2 plate area.

2. Density of insulating materials (kg/m^3):

Foam glass: 150; Mineral woll: 130; Fiberglass: 100; Calcium silicate: 200.

Bottom concrete weight:

$$W_{bottom\ concrete} = \rho_{\text{concrete}} \times \text{V}$$

Top roof weight:

$$W_{top\ roof} = W_{outer} - W_{inner} = \rho(\frac{\pi h}{6} \times (3a^2 + h^2) - \frac{\pi h'}{6} \times (3a'^2 + h'^2))$$

Inner tank weight:

$$W_{inner} = C_w \pi \rho_m D_m g(H_v + 0.8D_m) \times t \times 10^{-3} \qquad [14]$$

Outer tank wall weight:

$$W_{outer} = C_w \pi \rho_m D_m g(H_v + 0.8D_m) \times t \times 10^{-3} \qquad [14]$$

Part of isolation weight

$$W_{isolation} = C_w \pi \rho_m D_m g(H_v + 0.8D_m) \times t \times 10^{-3} \qquad [14]$$

Fittings:

There are three major factors that we should consider about: platform, ladders (stairways) and liquid loading.

$$W_{fitting} = W_{platform} + W_{stairways} + W_{liquid}$$

$$W_{liquid} = \rho V = 200000m^3 \times 476\frac{kg}{m^3} = 95200ton$$

$$W_{stairways} = \frac{FS}{g} = \frac{360\frac{N}{m} \times 60m}{9.81} = 2202kg = 2.2ton$$

In this case, we choose the total platform area with top platform and surrounding platform is 1/6 of the outer tank cross-area.

$$W_{platform} = \frac{\frac{1}{6} \times 1.7\frac{\text{KN}}{m^2} \times \frac{3.14 \times 91^2}{4}}{9.81} = 187ton$$

In addition, the total weight with LNG of this tank is;

$$W_{total} = W_{inner} + W_{outer\ wall} + W_{isolation} + W_{fitting} + W_{top\ roof} + W_{bottom\ concrete}$$

$$W_{total} = 2000 + 4712 + 3556 + 95469.3 + 2255 + 14217 = 122210\ \ ton$$

$$W_{total}(net\ \ weight) = 2000 + 2225 + 187 + 2.2 + 4712 + 3556 = 12725\ \ ton$$

$W_{bottom\ concrete}$	$14217\ \ ton$
$W_{top\ \ roof}$	$2225\ \ ton$
W_{inner}	2000 ton
W_{outer}	4712 ton
$W_{isolation}$	3556 ton
$W_{fitting}$	$95469.2\ \ ton$
W_{total}	$122210\ \ ton$
$W_{total}(net\ \ weight)$	$12725\ \ ton$

8.6 Reinforcement of multiple opening analyses

8.6.1 General description

At the installation of LNG storage tank, the pipelines hole will reduce the inner pressure which can affect the inner pressure balance. The reinforcement of multiple analyses will be used to consider about pressure change with opening reinforcement area. Based on the API-620, if the thickness of LNG tank is bigger than 3/8 in and the pipe size is smaller than 2 in [12]. This design comes with pipes sizes bigger than 2 in, which means it is necessary to do the opening analyses.

As mentioned, the LNG tank is a multiple opening system and the opening circle comes with diameter 2.5 m.

8.6.2 LNG tank opening analyses

Base on the API-620, for the 'needed opening reinforcement area', the following equation will be used;

$$\mathrm{A} = \mathrm{d}\delta + 2\delta\delta_{et}(1 - f_r) \qquad [15]$$

$$\mathrm{A} = \mathrm{d}\delta + 2\delta\delta_{et}(1 - f_r) = 2500\ \ mm \times 15\ \ mm = 37500\ \ mm^2$$

For the effective arrangements of reinforcement wide;

$$\mathrm{B} = \max\begin{cases} B = 2d \\ B = d + 2\delta + 2\delta_{et} \end{cases}; \text{So } \ \mathrm{B} = \ \ 5000\text{mm} \qquad [15]$$

For the effective reinforcement area;

$$A_1 = (B - d)(\delta_{et} - \delta) - 2\delta_{et}(\delta_{et} - \delta)(1 - f_r) = 2500mm \times 5mm = 12500mm^2$$

For the connecting reinforcement area;

$$A_2 = 2l_1(\delta_{et} - \delta_t)f_r + 2l_2(\delta_{et} - \delta_t)f_r \qquad [15]$$

$$l_1 = l_2 = \sqrt{d\delta}$$

$$l_1 = l_2 = \sqrt{d\delta_{et}} = \sqrt{3000mm \times 20mm} = 245\text{mm}$$

$$A_2 = 2l_1(\delta_{et} - \delta_t)f_r + 2l_2(\delta_{et} - \delta_t)f_r = 4 \times 245 \times (35mm - 0.5mm) = 33180mm$$

For the welding area; (welding leg =15mm) [16].

$$A_3 = 2 \times 0.5 \times 15^2 = 225mm^2$$

The total area of reinforcement;

$$A_{total} = A_2 + A_1 + A_3 = 46535mm^2$$

$$A_{total} > \text{A} \ \ (\text{enough, no need for other reinforcement})$$

9. Process design of heat leakage with checking

9.1 The limitation of heat leakage

Usually, LNG leaks in two forms continuous and transient leakage where, the leaking time to the dispersion time different with the continuous type leaking longer than dispersion time and shorter for transient type [12]. Heat leakage will check for several possible sections of the tank. Base on the chemical engineering design principle (AP-620 or GB-150 or EN-14620). When the boil-off rate is 0.25 vol. %/day, the following equation will be used for calculating the total heat leakage limitation;

$$\text{Q}_{total} = \Delta G \times q = n \times G_o \times q$$

$$\text{Q}_{total} = \Delta G \times q = n \times G_o \times q = 0.25\% \times 426 \times 200000 \times \frac{509 \times 1000}{24 \times 3600} = 1250kw$$

9.2 Heat leakage- from isolation part

$$\text{Q}_a = \lambda_e \times A_m \times \frac{\Delta T}{\delta} = 0.09 \times 9917 \times \frac{25-(-180)}{1.2} = 152kw$$

9.3 Heat leakage- from bottom part

From the Chapter 5.3.1 heating system, the power of bottom heating is 132.7 kw which means the leakage from bottom part is Q_b=132.7kw.

9.4 Heat leakage- from pipelines

As mentioned, pipelines of tank are LNG input and output, Condensed LNG input, perlite input and BOG output pipelines. Therefore, the overall heat leakage from the tank can be calculated as below:

$$Q_c = \lambda_d \times \frac{A}{L} \times \Delta T = 36 \ \ kw$$

9.5 Heat leakage- checking

The total heat leakage can be calculated by summation of all parts leakage heat as below:

$$\text{Q} = Q_a + Q_b + Q_c = 152kw + 132.7kw + 36kw = 320.7Kw < 1250Kw = Q_{total}$$

Which means the overall heat leakage is acceptable.

10. Conclusions

Many design codes combined to design storage tank of liquified natural gas in efficient way to reduce the energy losses. The designed tank is competent to store liquified natural gas with capacity up to 200000 m^3. This work introduced efficient chooses based on different design codes to design the tank. Where, the proposed design reduced the heat leakage by using effective isolation with thickness up to 1.2 m. The design diameter was 85 m and 37 m height to the requested function of storing 200000 m^3. The possible heat leakage has been checked with detail analysis which is in the acceptance range. The proposed method resulted efficient design with high performance in storing high capacity of LNG. The reconditions can be illustrated by;

1- The amount of boil off gas should be studied in detail.

2- high system control should be examined.

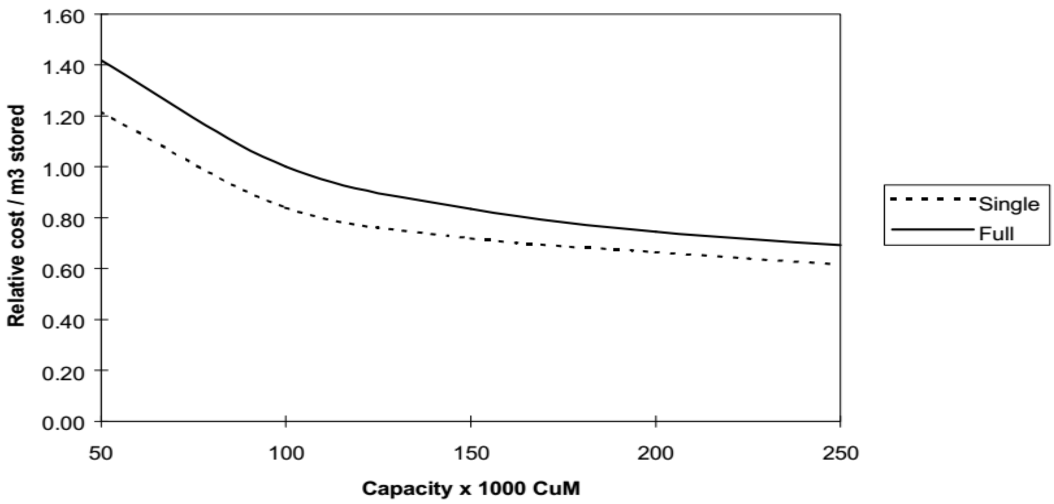

Fig (1): Unit Cost Ratio vs Tank (Usable) Capacity [1]

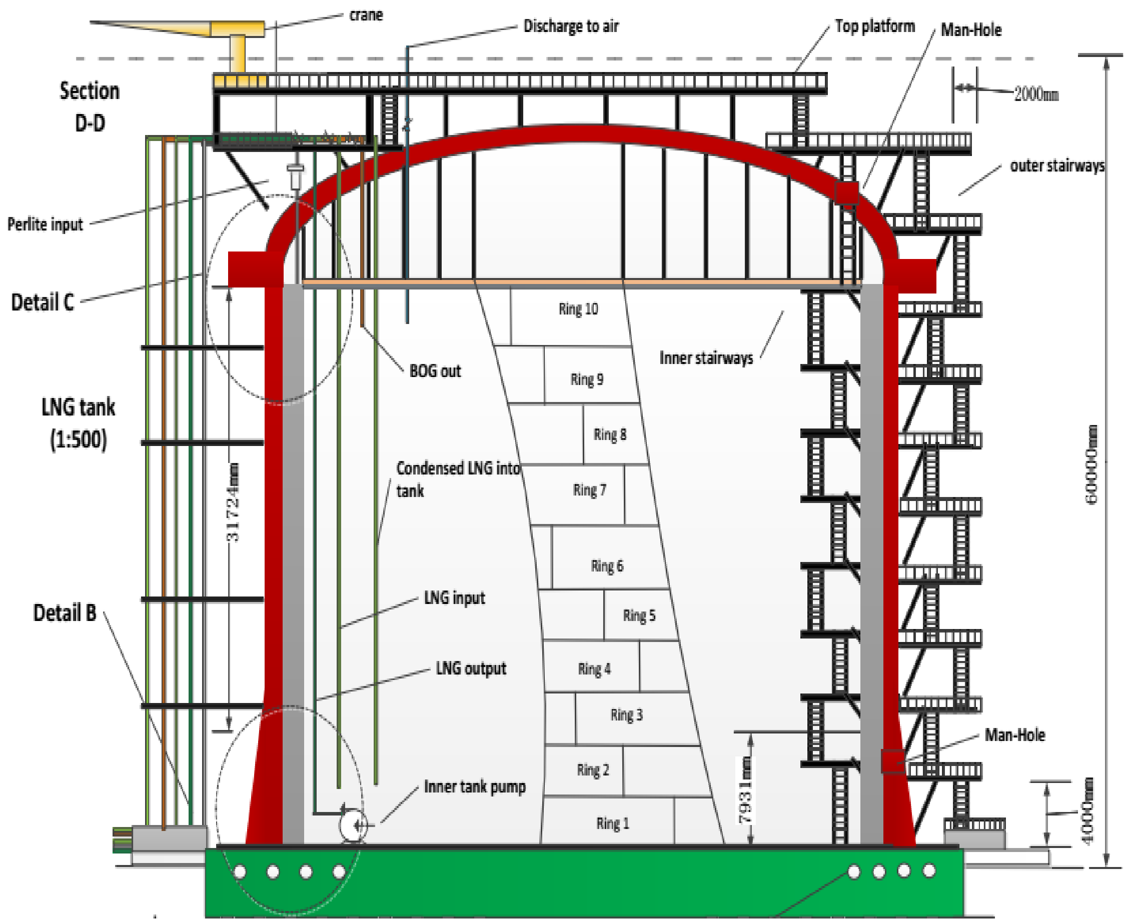

Fig. (2): The parts of LNG tank

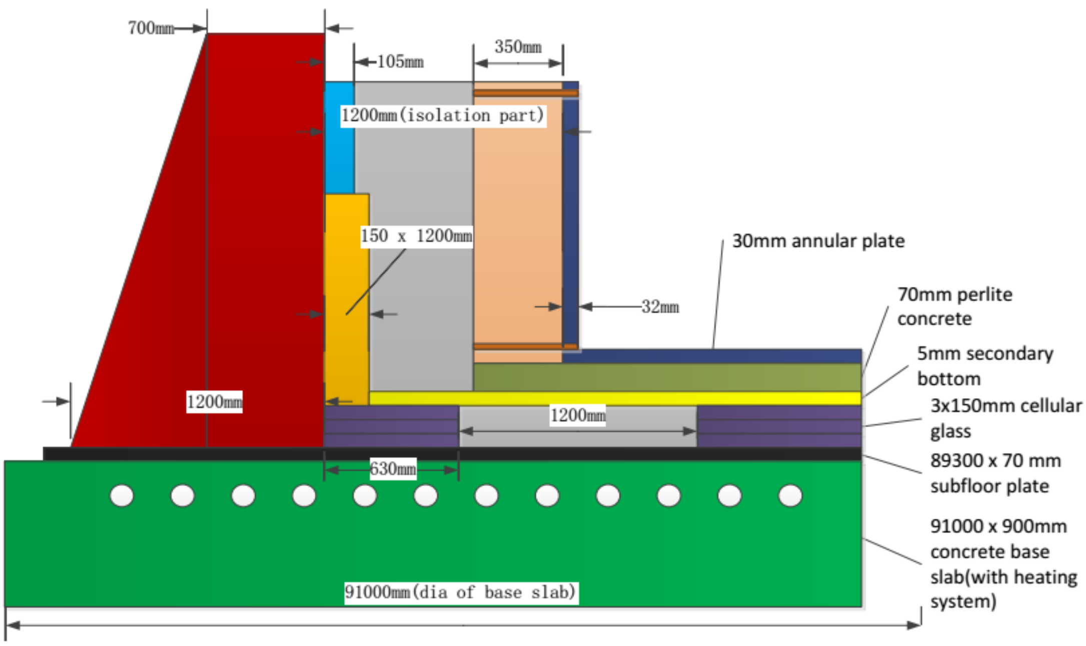

Fig. (3): Bottom of tank and corner protection

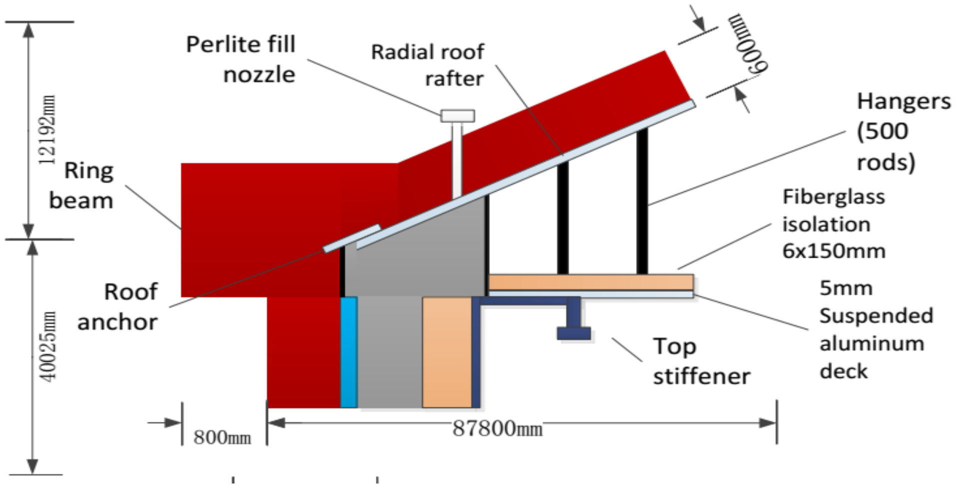

Fig. (4): Top of tank and corner protection parts.

Table (1): LNG storage tanks with the largest capacity [4]

Type		Capacity (m^3)	Location
Aboveground	Concrete roof type	200,000	Tongyeong (Korea) Pyeongtaek (Korea)
	Steel roof type	200,000	Darwin (Australia)
In ground		200,000	Negishi (Japan) Incheon (Korea)
Underground		200,000	Ohgisima (Japan)

Table (2): General data for 200,000 m3 of LNG tank used in this work

	Items	Descriptions
General specification	Type of tank	above-ground, full containment
	Inner tank materials	9 % nickel steel
	Outer tank materials	pre-stressed concrete
	Roof	concrete dome with suspended ceiling deck
	Secondary barrier	9 % nickel steel corner protection system up to 5 m high from the Tank bottom then polyurethane foam (PUF) coating
	Type of base	brine heating system (BHS)
	Gross capacity	200,000 m^3
	Seismic requirements	SSE 0.2g, OBE 0.1g
	Design pressure	29 kPaG
	Design temperature	-170^{o}C
	Design boil-off rate	0.25 vol%/day
	Maximum liquid feed rate	11,000 m^3/ hr
	Specific gravity of LNG	0.48
	Vertical seismic response	2/3 of horizontal values

Table (3): Tank dimensions for unit size calculations [4]

Capacity (m^3)	D_i (m)	D_o (m)	H_i (m)	H_o (m)
50,000	52	54.4	25.68	27.97
100,000	65	67.4	32.31	34.61
150,000	75	77.4	36.14	38.44
200,000	85	87.4	37.44	39.74
250,000	90	92.4	41.52	43.80

Table (4): Specific data of stiffening rings

number of shell course	thickness for each plate (mm)	minimums thickness (mm)	Ls (space between plate) (mm)	Size (mm)
1	32.1	11	3742.2	382x32.1
2	24.7	11	3742.2	382x24.7
3	24.7	11	3742.2	382x24.7
4	21.5	11	3742.2	382x21.5
5	18.2	11	3742.2	382x18.2
6	15	11	3742.2	382x15
7	12.7	11	3742.2	382x12.7
8	11	11	3742.2	382x11
9	11	11	3742.2	382x110
10	11	11	3742.2	382x11

Table (5): Specification of outer material

Design pressure	0.1 MPa	Coefficient of welding joint	0.85
Design temperature	50 ℃	Corrosion allowance	1 mm
Inner diameter of outer concrete tank:			86400 mm

Table (6): showing some parts and the function for each one

Part Name	Function
Corner protection	uses instead of polyurethane foam at the corner to carry more pressure load**.**
Cellular glass	uses to prevent the LNG from cracking at the lower concrete wall section
9% nickel steel plates	uses to prevent LNG from cracking at the lower concrete wall section
Outer wall	lower half of height has varying thickness and remaining upper half constant thickness to carry more pressure load.
Perlite concrete	there is a 1200mm length perlite concrete instead of cellular glass at the bottom as the buffer.

Table (7): bottom plate parts with thicknesses

Section Name	**Location**	**Thickness**
Perlite concrete	under the annular plate	70 mm
Secondary bottom	buffer between cellular glass and perlite concrete	5 mm
Cellular glass	lower concrete wall section	3x150 mm
Subfloor plate	between cellular glass and concrete base slab	70 mm

Table (8): Several different parts

Part Name	Function	Specifications
Perlite fill nozzle	filling Perlite concrete	105 mm diameter and 800 mm length
Roof anchor	holding the roof plate	
Ring beam	to deal with major portion of the thrust transmitted from roof dome thus to reduce excessive deformation of upper part of the wall	
Hangers	to hold the whole roof	this design 500 rods used to support the entire roof
Suspended Deck		thickness of the deck plate is 5 mm
Fiberglass isolation	to isolate the outer tank and LNG at top of tank.	150 mm thickness of per layer.

Nomenclature

P_c is the total pressure	D_i is the inner tank diameter
Σ_k is the yield strength $= 225mpa$ (9Ni steel, at specific temperature $-180C^0$)	θ is the Coefficient of welding joint $= 1$
λ ; The coefficient of thermal conductivity of insulation materials $(0.09-0.23)(\frac{w}{m}.K)$ (Polyurethane foam, resilient glass fiber, perlite concrete)	a_s; Thermal barrier exterior surroundings exothermic coefficient$(\frac{w}{m}.K)$
D_{in} is the inner tank diameter (m)	T_s is surface temperature
T_a is surrounding temperature	T_f is perlite concrete temperature
P is vacuum degree,	D is thickness of inner tank
e_{min} is minimum thickness of stiffness rings.	E; Young's modulus
Kc; Collapse coefficients,	t; shell thickness for inner tank
Do; inner tank diameter	Kc; Collapse coefficients,
t; shell thickness for inner tank,	λ; average thermal conductivity
φ; average heat intensity	t_{w2}; 110k and t_{w3}; $283k$ *and* t; $273k$
δ_{tot}; total thickness with fundation	
x; thickness without fundation and concrete slab	t is minimum thickness of the doom
Pi is internal pressure 1.5mpa	Di is diameter of the tank (89.4m)
E is welded joint efficient (1)	S is maximum allowable stress 117.8N/mm2
h is the height of roof part (12.1m)	A is half of the outer diameters (91/2 m)
h' is the height of roof part without the roof wall (12.1-0.6m)	a' is half of the outer diameters without the wall thickness (91/2-2x0.6m)
ρ is the density of carbon steel $(7791\frac{kg}{m^3})$	W= total weight of the shell, excluding internal fittings, such as plates, unit: N
C_w= a factor to account for the weight of nozzles, man ways, internal supports, etc.: which can be taken as = 1.08 for vessels with only a few internal fittings = 1.15 for distillation columns, or similar vessels, with several man ways, and with support rings, or equivalent fittings.	H_v= height, or length, between tangent lines (the length of cylindrical section), unit: m

ρ_v = the density of vessel material, kg/m^3	D_m= mean diameter of vessel = Di+ tx10^{-3}.
A is needed opening reinforcement area ;	d is circle area diameter (d = 2.5m)
δ is thickness of inner head(shell cover = 15mm);	f_r is the coeffiecient of weakness = 1
δ_{et} is effective thickness ofinner head (shell cover = 20mm)	l_1 is the effective height of outer connecting
l_2 is the effective height of inner connecting	δ_t *is thickness of connecting* (*assume* 0.5*mm*)
Ws; safety discarge rate of LNG (kg/h)	t; saturation temperature of flow (under the discharge pressure)(117 °C)
λ ;*The coefficient of thermal conductivity of insulation materials* (0.09 − 0.22)($\frac{w}{m}.K$)(need convert to $\frac{kJ}{h.m.K}$)	δ; thickness of isolation part between inner and outer tank (1.2m)
q; heat of evaporation of liquefied gas (509.74$\frac{KJ}{Kg}$)	Ar; heating area at inner tank (m^2)
D; the diameter of inner tank (m)	H; liquid maximun level at inner tank (m)
K; adiabatic index of ideal gas (K = 1.3)	k; discharge coefficient which relaed to the structure of valve (0.6~0.7)
M; molar fraction of natural gas (17.8Kg/kmole)	Z; compressibility factor of LNG under the operating pressure and temperature (Z = 0.8)
T; The temperature of LNG after discharge (T = 156K)	P_d; Discharge pressure though safety valve (P_o = 1.12mpa)
P_o; outlet pressure (P_o = 0.1mpa)	λ_e: effective thermal conductivity $\left(0.09\frac{w}{m}.k\right)$
A_m: surface area of inner tank (A = πHD = 3.14 × 84m × 37.6m = 9917m^2)	δ: thickness of isolation part(m)
ΔT; temperature difference for two side	λ_d: thermal conductivity of stainlesssteel ($\frac{9.62w}{m}.k$)
A: section area of pipelines (steel part).	L: lenth of pipeline inside of tank part
$n: boil-off\ rate\ \frac{vol\%}{day}$.	q: *heat of LNG evaporation* (J/kg).
G_o: *mass of LNG in the tank* (kg)	
W the load per unit length (Newton's per meter).	L_S is the spacing between the rings.
M is the vertical moment	t is thickness of the wall.
q: flow rate inside of pipes.	W: velocity of flow

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تصميم فعال لخزان كبير لخزن الغاز الطبيعي المسال

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الخلاصة

يعتبر الغاز الطبيعي واحد من مصادر التي تنتج طاقة نظيفة قليلة الانبعاثات شديدة الكثافة وصديقة للبيئة. لنقل الغاز الطبيعي، من المهم جدا تحويل الغاز الطبيعي الى الحالة السائلة لتقليل خسائر عملية النقل، لذلك تصميم خزانات لحفظ الغازي الطبيعي المسائل يعتبر من العوامل التي تساعد على دعم تجارة الغاز الطبيعي. تتميز خزانات الغاز الطبيعي المسال بحجومها الكبيرة جدا التي تصل الى ٢٠٠٠٠٠٠ متر مكعب. يعتبر تصميم خزانات الغاز الطبيعي تكنلوجيا جديدة للكثير من الدول. تتميز خزانات الخزن بسمك عزل عالي يصل الى متر في بعض الاحيان لان الغاز المسال يكون عادة بدرجات حرارة منخفضة تصل -١٦٥ درجة سيليزية. هذا التصميم يجمع بين عدة كودات تصميم لدراسة تفصيلية لعملية تصميم خزان غاز مسال يشمل مايلي الهيكل الداخلي والخارجي للتصميم، تصميم قاعدة الخزان، تصميم الجزء العلوي من الخزان. بالاضافة الى ذلك، التصميم يتناول محاكاة تفصيلية للحرارة المتسربة من كل جزء من الخزان ليتبين ان التصميم يعمل بكفاءة عالية والحرارة المتسربة ضمن الحدود المقبولة.

الكلمات المفتاحية: الغاز المسال، خزان، تصميم ميكانيكي، تصميم حراري.