

# The selection of Sufficiently Efficient ISO LNG Tanks for Applications in Industrial Estates based on Edward Lisowski and Wojciech Czyzycki

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## **Abstract**

*Liquefied Natural Gas (LNG) is more likely to employ gasoline in street transportation applications because of its greater cryogenic energy density as a result, the key problem with this technology is the tank mounted on board with the control system and vaporizer board required to give the internal combustion engine (ICE) input. The research approach employed in this study was quantitative research using experimental methodologies because this study necessitates controlling and manipulating one or more independent variables while observing the dependent variable to detect differences based on the independent variables. With a method like this, of course, a tank that is quite efficient can be selected. In terms of profit, it is apparent that it could produce a greater volume of gas than gas to liquid (GTL), because the project of LNG lifespan was more extensive than GTL's. LNG is thus more commercial than GTL.*

**Keywords:** Design, Tank, Efficient

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## **INTRODUCTION**

Indonesia has large gas potential. National oil reserved 4.17 billion barrels and it could prove that it reserved 2.44 billion barrels. Meanwhile, data on unproven reserves was 2.44 billion barrels. Natural gas' chemical features were undeniable proof of the sophisticated behavior, an environmental as the point of view, of a fuel that emits less



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CO<sub>2</sub> (due to its carbon-hydrogen balance) and less NO<sub>x</sub> and PM than other fuels. [1]. Its increased energy density, liquefied natural gas (LNG) allowed for the use of this fuel in heavy-duty road transportation applications. The biggest challenge with this technique is the cryogenic tanks put on ships with thermal behavior control, which require a temperature of -162 C (at atmospheric pressure) to keep the fuel in a liquid state. To fuel an internal combustion engine, you would require systems and vaporizer boards (ICE) [1]. This aspect (onboard cryogenic vessels) and others, like refueling infrastructure, still required some standardizations of working, which is now being worked on at the ISO level. In this perspective, the L-CNG gas station concept was an intriguing new option for refueling infrastructure. Because it could provide LNG and CNG, this application was suitable for all types of gas-powered cars. A liquid cryogenic pump at 300 bar provided the compressed gas, which was then released at 200-250 bar by a downstream vaporizer. When it compared to traditional filling stations that used compressors to make CNG from piped gas, this method consumed less energy [2]. The next sections would discuss LNG base load generators (0.3 to 2 MTPA ) on a modest to medium scale in table 1.

**Table 1.** Modest to medium scale LNG baseload generation (0.3 to 2 MTPA) [2]

No	Location	Merk	Status	Capacity (MTPA)
1	Australia	Fisherman's Landing LNG	Front	1.5
2	Australia	Galveston LNG	Proposed	1.3
3	Australia	SUN LNG	Front	0.5
4	China	DaZhou LNG	Under Repair	0.5
5	China	Ordos LNG 2	Not Known	0.3
6	China	Shan Shan	Generator Operation	0.4
7	China	Shanxi LCBM 2	Not Known	0.3
8	China	Xinjiang Guanghui New Energi Company Syngas & LNG Plant	Proposed	0.4
9	East Timor	Flex LNG Australasia FPSO	Proposed	1.5
10	Indonesia	Donggi Sen	Proposed	2
11	Indonesia	Sengkang LNG	Under Repair	2 (4x0.5)
12	Iran	Qeahm - LNG Limited	Proposed	0.9
13	Nigeria	Flex LNG/Mitsubishi/Peak Petroleum Nigeria FPSO	Under Repair	1.5
14	Norwegia	Nordic LNG	Under Repair	0.3
15	Papua New Guinea	Flex LNG/Rift Oil LNG FPSO	Proposed	1.5
16	Papua New Guinea	PNG - LNG Limited	Proposed	2.6 (2x1.3)

Indonesia's conventional gas reserved 150 tcf and these data making further gas exploration unprofitable [3]. In accordance with what has been explained regarding the background of the research, there were several problem limitations such as getting a good design calculation so that it is easy to apply LNG in Indonesia, knowing the feasibility of applying LNG in Indonesia and making the LNG Tank an efficient tank, knowing the LNG distribution process with an efficient value if compared to other gases. The purpose of this research was to be able to apply the LNG system for daily needs in Indonesia on a mass scale, to be able to make an example as an ISO-licensed worthy tank, to get results that are quite economical for LNG compared to other types of gas. In this study, it had benefits based on research objectives. They were being able to reduce the energy crisis due to fuel scarcity, being able to apply LNG to the community both on

a small and large scale, being able to minimize pollution from gases that have pollutants in general (conventional) such as LPG so that LNG becomes environmentally friendly gas fuel.

**Table 2.** Explanation Related to Referring to Previous Research

No	Title/Author/Year	Method	Research Result
1	Estimating Capital Cost of Small Scale LNG Carrier. M. Habib Chusnul Fikri, Jooned Hendrarsakti, Kriyo Sambodho, Frengki Mohamad Felayati, Nilam Sari Octaviani, Mohamad Jeffry Giranza, and Gregorius Andrico Hutomo. 2018	The methodology is using empirical equation to estimate the overall ship construction cost. The ship structural weight, outfitting weight, diesel engine weight and remainder weight. After that, the cost of the ship construction is estimated using weight based estimation.	A method to estimate the building cost of small scale LNG carrier was presented. Furthermore, this method was used to derive easier-to-use rules of thumb for the cost of small scale LNG ship for which only cargo volume, engine power, length, width height and draught of the ship are known.
2	Three-dimensional sloshing in a scaled membrane LNG tank under combined 2 roll and pitch excitations. Min Luoa , Xin Wanga , Xin Jinb , Bin Yan. 2020	This setup was successfully used to study the water sloshing 108 under resonant and random excitations with the experimental data utilized to validate a numerical model.	This study investigates the violent sloshing in a scaled membrane-type LNG tank whose length-to breadth ratio is around 1.4. The coupled roll and pitch motions, which have been rarely documented in the literature, are considered. Seven groups of roll and pitch amplitudes are tested. In each group, 9 - 11 excitation frequencies are studied with refined frequency points near the transition of the waveform.
3	Analysis and Optimization of Atmospheric Drain Tank of Lng Carrier Steam Power Plant. Igor Poljak,Toni Bielić, Vedran Mrzljak and Josip Orović	During that process, feed water is taken from the main condenser, where the steam outlet from the main turbine and turbo generators condenses at saturated steam pressure. The temperature of the condensate water depends on the vacuum and seawater cooling temperature and varies from 30 to 40 ° C.	According to an exergy analysis in port and at lower loads, it is clear that desuperheating water at the fresh water generator line, which comes from the main condenser feed water line, should be kept closed as fresh water generator is not in service and there is no steam for cooling down the fresh water generator.

Before taking action on the novelty of the research or the focus of research that has been raised in depth on this topic, it was better if the previous step needed to be explained about the explanation related to the title, method and conclusions with reference to previous research. The following will be explained in Table 2.

Based on what has been described in the background, problem boundaries, research objectives and benefits as well as state of the art based on previous research, the novelty or gap of this research is to get a more acceptable and feasible type of tank in terms of efficiency if applied to an industrial scale in Indonesia with some related parameter benchmarks.

The relatively high cost of producing LNG and the need to store it in expensive cryogenic tanks have prevented its widespread commercial use. Despite this shortfall, on an energy basis, LNG production was estimated to account for 10% of global crude oil production by 2020. The following describes an illustrative capital expenditure profile for the selected LNG project collecting two 3.3 modern monetary theories (MMT) works and a \$3.85/annual field investment in million British thermal units (MMBTU) [4].

The discovery of superconducting materials with critical temperatures substantially was higher than liquid nitrogen's boiling point which had reignited interest in low-cost, dependable ways for generating high-temperature cryogenic refrigerants. Temperatures ranged from above the boiling point of liquid nitrogen, 195.79 °C (77.36 K; -320.42 F), to 50 °C (223 K; 58 F), the upper limit of which studied were widely defined as cryogenics, were referred to as "high-temperature cryogenics." Cryogenicists employ the Kelvin or Rankine temperature scales, which both measure from absolute zero, rather of the more prevalent Celsius or Fahrenheit temperature scales, which have zero at a variable temperature. The following would show the comparison in terms of properties in Table 3.

**Table 3.** Comparison in terms of properties[5]

No	Properti	Gas Alam	LPG	Propana	FO	LDO
1	Nilai Kalor Kotor (Kcal/kg)	12953	11500	11200	10200	10500
2	Flammability Range in Air (%)	5-15	2-9	2.2-9.5	-	-
3	Gross Calorific Value (°C)	1964	1970	1960	1000	1050
4	Flas Point (°C)	-188	-104	-110	66	66
5	Boiling Point (°C)	-161	-27	-42	204	350
6	Poison	No	No	No	Yes	Yes
7	Dirt	No	Low	Low	High	High
8	Spill	Evaporates and Dissipates into the Air	Setting Near Ground Level	Setting Near Ground Level	Forms Surface Pool	Forms Surface Pool
9	Friendly	Yes	Yes	Yes	Yes	No

In 2003, Japan accounted for 67 percent of Indonesia's LNG exports, accounting for the majority of the country's commerce. The rest of Indonesia's LNG exported that year went to Korea and Chinese Taipei, accounting for 19% and 13% of the country's LNG trade, respectively. The trade flows were a reflection of Indonesia's long-term LNG supply contracts with Japanese, Korean, and Chinese Taipei energy corporations. The yearly amount of long-term contracts was close to 27 million tonnes in 2004 [6]. Indonesia exported 26.0 million tonnes of LNG in 2003, accounting for 21% of global LNG commerce. Since 1999 lower export volumes reflect the decommissioning of the

two Arun railways in 2000, followed by a seven-month production shutdown at the Arun facility in 2001 due to political upheaval in Aceh [7].

There were just four physical techniques that are utilized to produce cryogenic temperatures and environments: evaporative cooling, fast expansion cooling, heat conduction (Joule-Thompson effect), and adiabatic demagnetization [8]. Chart Industries offered a wide range of LNG satellite plants and multifunction terminals – enabling the use of natural gas in locations off the natural pipeline. Liquefied natural gas storage terminals were designed to meet customer requirements for storage capacity and flow using a modular design and standard components [9]. Based on data from Broadview Energy Solutions, the maximum allowable working pressure was 145 psi and tare weight with a load capacity of 10 items or 145 psi. The minimum water capacity was 45500 L and a maximum of 47000 L, while the minimum tare weight was 12500 kg, and the maximum is 13200 kg [10].

LNG offers greater flexibility than piped gas in volume, distance & area spread. LNG was more efficient than CNG because CNG is equivalent to 120 times natural gas at a temperature of 15 Celcius and a pressure of 1 atmosphere. At a temperature of 15 degrees Celsius and a pressure of 1 atmosphere, LNG is 600 times natural gas. 1 tank of LNG is equivalent to 5 tanks of CNG. ISO LNG Tanks could be transferred by land transportation (trucks, trains), and sea transportation (tugs & barges, LCT, SPB). The potential market for LNG ISO Tank was around 1,150 units until 2024 (the ISO equivalent of total gas power plants is 120 units (13,700 MW)) [11].

## METHODS AND ANALYSIS

The research method used in this study was experimental research because this study necessitated controlling and manipulating one or more independent variables while observing the dependent variable in order to determine differences based on the independent variables. LNG could be used as energy or alternative fuel to replace diesel or diesel. Because it had several advantages, including colorless, odorless, and non-toxic, so it is safe to use. In the distribution of LNG, LNG ISO tanks were needed because to facilitate the distribution of LNG. In this study, we would discuss further about LNG ISO tanks.

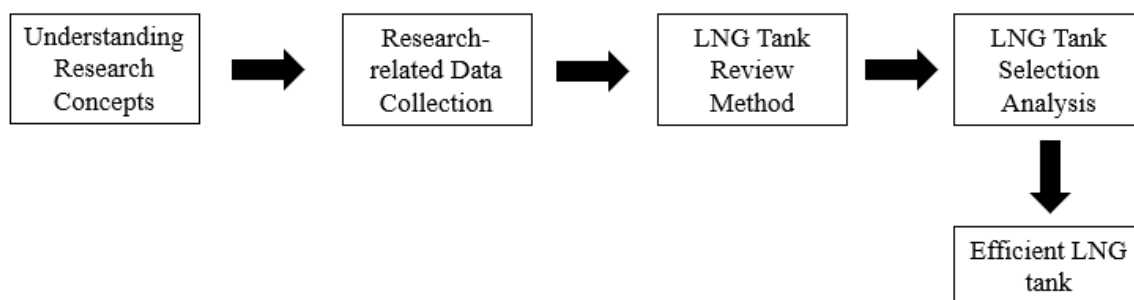


Figure 1. Research Chart

In making this research, the first step was to know the research problem. Because in Indonesia, LNG had not been maximally developed in daily life, gas development is more dominant in LPG and CNG. Then at the literature study stage, it was more emphasized to look for references from journals, websites, etc. After knowing the research reference sources, it created the LNG ISO Tank design concept. Then, it conducted a simulation analysis. Next, It did a good type of material in order to have an advantage when it did calculation analysis. This calculation analysis included mechanical

and business calculations. After the calculation results were obtained, the researcher took some data to be used as research references which would later be used as the advantages of this research. And finally, the research conclusions were made. The following would explain the research flow chart in Figure 1.

Heat transmission to the tank could occur in three methods because of higher temperature difference with medium temperature and the environment. They were conduction, convection, and radiation. This approach can be determined using the heat transition theory. Heat conduction in the designed tank occurs through the tank walls, supports, pipe fittings and other elements connected to the tank. For LNG tanks, the temperature difference between the transported liquid and the outside environment can reach 200 K or even more, under certain conditions. In this case, the heat conduction process could be described as a one-dimensional problem under steady-state conditions. This process can be described by the Fourier equation (1) [12].

$$q = -\lambda \cdot \text{grad} (T) \quad (1)$$

Where  $q$  is Basic heat flux [W/m<sup>2</sup>],  $\lambda$  is Thermal conductivity [W/(m.K)], and Grad (T) or  $\partial T / \partial n$  is the temperature derivative in the direction - perpendicular to isothermal surface.

Thermal conductivity under cryogenic conditions was highly temperature dependent. Therefore, this dependence should be considered during calculations. Under cryogenic conditions, convection in LNG tanks was identical to convection at higher temperatures. Newton's equation (2) could be used to calculate the heat transfer from the tank wall to the liquefied gas [13].

$$Q = \alpha \cdot F \cdot (T_s - T_f) \quad (2)$$

Where  $\alpha$  is the heat transfer coefficient [W/(m<sup>2</sup>K)],  $F$  is surface area of the solid body [m<sup>2</sup>],  $T_s$  is temperature of the solid surface [K], and  $T_f$  is the temperature of the liquid [K]. The value of the heat transfer coefficient, which was normally measured experimentally, it was required to use the equation. The Nu, Re, Pr, and other similarity values required to represent convective heat transfer are determined by the fluid's thermal and transport parameters. Thermal conductivity ( $\lambda$ ), viscosity ( $\mu$ ), thermal capacity ( $c$ ), density ( $\rho$ ) and others were examples of the qualities. These qualities were significantly temperature sensitive under cryogenic settings. As a result, the heat transfer coefficient must likewise be temperature dependent [12].

Thermal radiation was a natural phenomenon that occurs when the temperature rises above absolute zero. The following equation could be used to calculate the heat flux communicated by radiant heat between two bodies with temperatures  $T_1$  and  $T_2$  (assuming  $T_1 > T_2$ ) (3):

$$q_r = \sigma \cdot \epsilon' \cdot (T_1^4 - T_2^4) \quad (3)$$

Where  $\sigma$  is Stefan's Constant - Boltzmann ( $\sigma = 5.67 \cdot 10^{-8} \text{ W} / \text{m}^2\text{K}^4$ ),  $\epsilon$  is substitute the system's emissivity for the emissivity of the system under investigation, and  $T_1, T_2$  is temperature [K]. By putting a radiation barrier between two surfaces, thermal radiation

between them could be minimized. Temperatures between T1 and T2 were acceptable for shields. If the radiation shield and the heat-exchanging If the emissivity of the body surfaces was the same, the amount of heat exchanged by radiation between the surfaces with one shield was twice that of the surfaces without the shield. As a result, a larger number of shields improved radiant heat insulation efficiency. Because each radiation shielding occurred, the number of shields must be limited. Three radiation shields have been used in the insulation for the planned tank. [12].

For a two-wire cryogenic tank with fibrous insulation, acquired higher degree of vacuum ( $P \ll 0.1 \text{ Pa}$ ), time-needed, and costly processed. In addition, maintaining vacuum at high level could be difficult in favor of tank outgassing and insulation materials. The heat was conducted by the residual gas in the area between the tank walls. Heat transfer which was conducted radiation and residual gas conduction could be near to another in the tank under consideration, so this impact could not be disregarded. The leftover gas could not be treated as a continuous medium when considering the structure. As a result, Corruccini's formula (4) was utilized [12]:

$$q_{gr} = \frac{Y + 1}{Y - 1} a \left( \frac{R}{8\pi M T_p} \right)^{\frac{1}{2}} p(T_2 - T_1) \quad (4)$$

$$Y = \frac{C_p}{C_v}$$

$$a = \frac{a_1 a_2}{a_1 + a_2(1 - a_2) \frac{A_1}{A_2}}$$

The meaning were Cp is specific heat of air [J/(kg.K)] at constant pressure; Cv is air temperature at constant volume [J/(kg.K)];  $\alpha_1, \alpha_2$  is coefficient of heat transfer for the tank's surface section;  $A_1, A_2$  is the surface area of the inner and outside tank walls [m<sup>2</sup>]; R is gas constant [J/(mol.K)]; M is remaining gas molar mass [kg/mol]; Tp is pressure measuring point temperature (on the exterior tank) [K], P is pressure of residual gas (in Pa); and T<sub>2</sub>, T<sub>1</sub> is temperature of the inner tank's outside wall and the insulation's outer casing [K].

Several forms of insulations have been chosen for simulation research with the goal of determining the usefulness of cover the materials in the building of LNG tank containers. The simulation involved calculating the average heat flux for LNG emitted into the environment. The airgel (trade name cryo-lite) insulation was chosen for testing. Heat leakage could be calculated using the following equation (5) [12]:

$$L = \frac{86400 \cdot Q_c \cdot A}{h \cdot F} \quad (5)$$

Where Qc is average heat flux on the outer surface of the tank [W/m<sup>2</sup>], A is outer surface area of the tank [m<sup>2</sup>], h is latent heat of vaporization [J/kg], F is total mass of LNG in the tank [kg].

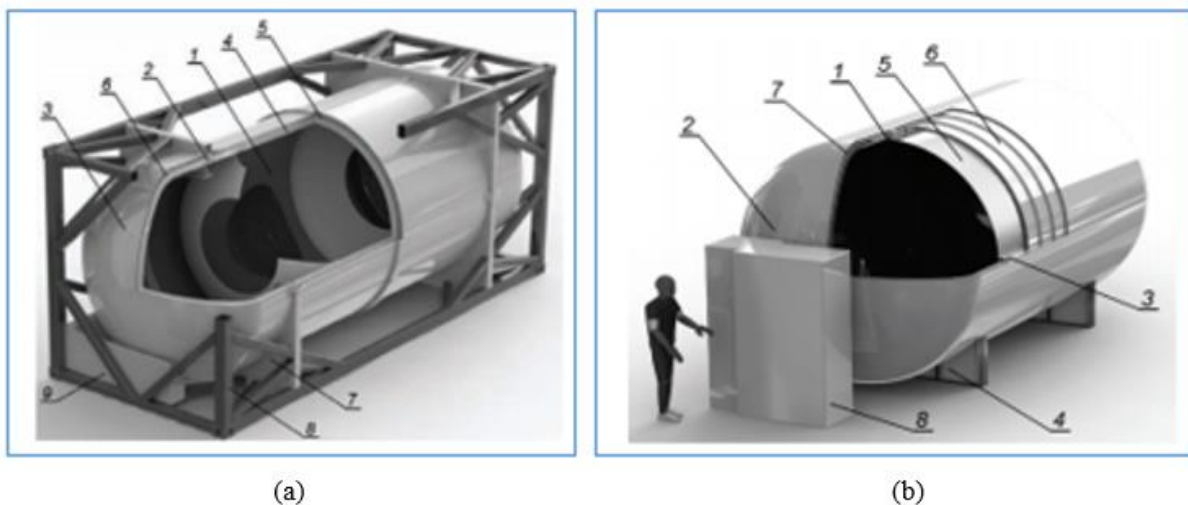
The following assumptions were made: the model is in thermal equilibrium, the inner tank wall's heat resistance is minimal, etc because it is negligible compared to the insulating material. Radiation shields are placed between the insulating layers. In a vacuum, only radiation was considered for heat transmission. The surface emissivity

coefficient was thought to be dependent on the surface's type and temperature. Furthermore, it only convection with a known constant coefficient transferred heat from the tank's outside surface to the environment. A plastic support structure was used to mount the inner tank on the outside. The contact surface between the support and the tank was where thermal contact resistance was measured [12].

Four versions of the cryogenic tank design were created with the aforementioned factors in mind, and simulations of the variants were performed. Various tank diameters and operating pressures of 7 and 12 bar were among the types:

- Type I - tank mounted on standard ISO TC 104 container frame with outer tank diameter  $D = 2350$  mm, length  $L = 5946$  mm, volume  $V = 19$  m<sup>3</sup> and operating pressure  $p = 7$  bar,
- Type II - tank built as variant I, but with reduced inner support dimensions for the sake of assuming that only empty tanks can be transported,
- Type III - a tank with an outer diameter of  $D = 3000$  mm and a length of  $L = 6058$  mm, which results in a volume of  $V = 32$  m<sup>3</sup>; operating pressure  $p = 7$  bar,
- Type IV - tank as in variant III, but increased operating pressure to 12.5 bar.

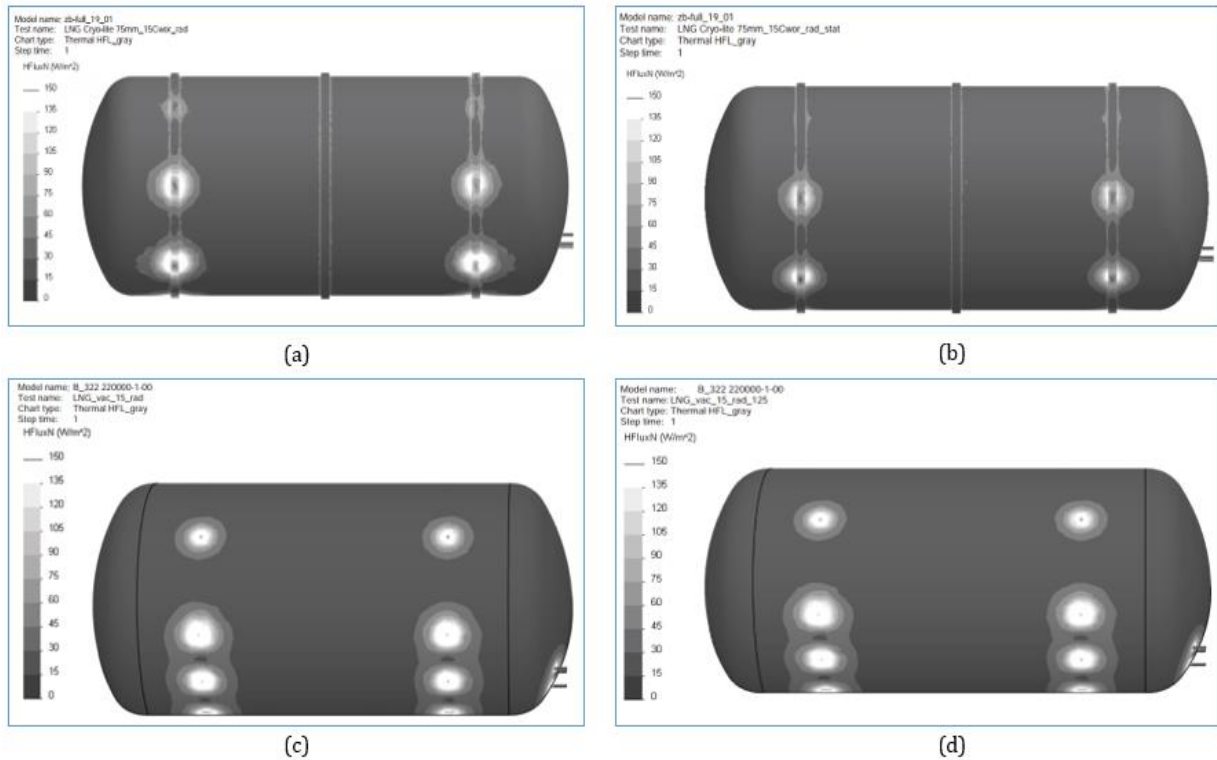
The ability to eliminate the computational instances associated with movement with loads necessitated some improvements (tank innovations). The shape of the support has been adjusted following a strength examination. The central section of the support has been narrowed. Furthermore, the number of supports at the tank's apex has been cut in half. Empty tanks could be transported using containers thanks to the architecture [12]. The following is a container model that will be explained in Figure 2.



**Figure 2.** a) LNG tank container model for LNG transportation and storage, b) Mobile LNG tank model [12]

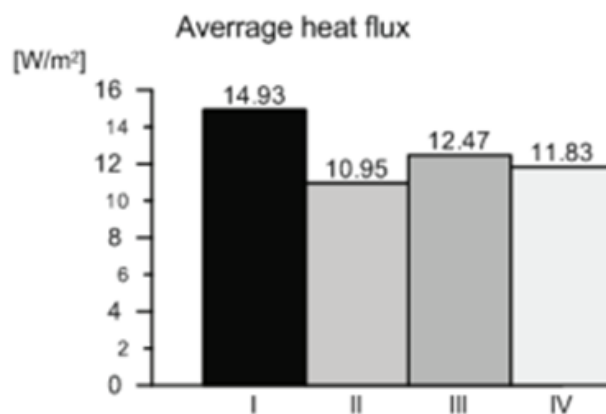
The distribution of temperature and heat fluxes was obtained as a result of the analysis. Figures 3.a and 3.b depicted the distribution of heat flux in the exterior tank for the construction variants for type I and II tanks, respectively, while Figures 3.c and 3.d depicted the distribution of heat flux in the external tank for type III and IV tanks, respectively. The largest heat flux values were found at the site of the inner support, as shown by the obtained data. Figure 3 would show you how to do this.





**Figure 3.** a) Heat flux on the outer surface of a type I container tank; b) Heat flux on the outer surface of a simplified type II container tank; c) Heat flux on the outer surface of a type III tank; d) Heat flux on the outer surface of a type IV stationary tank [12]

The average heat flux on the tank's exterior surface was computed with the help of the FEM model. The average heat flux across the tank's exterior surface was calculated using the FEM model. Figure 4 showed a comparison of average heat flux on the tank's exterior surface [12].



**Figure 4.** The average heat flux of different types of tanks [12]

## RESULTS AND DISCUSSIONS

By referring to secondary and related data in Figures 3 and 4 regarding heat flux, with the existing literacy, the values will be described in Figure 5 [12].

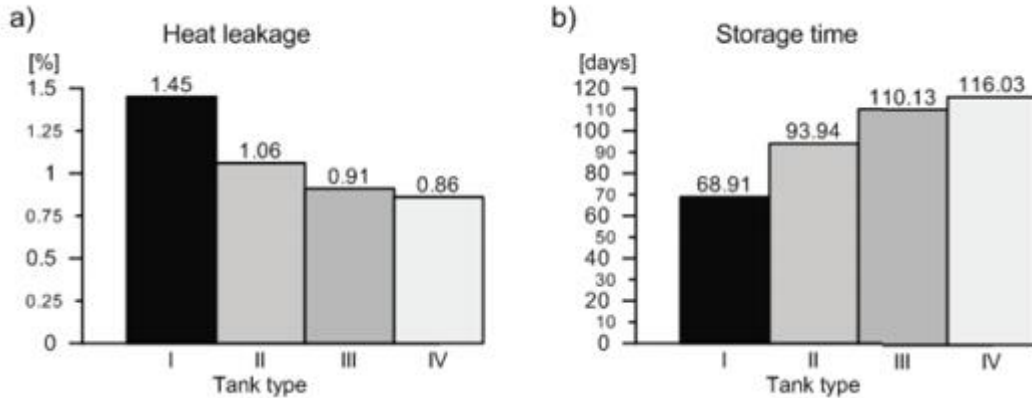


Figure 5. (a) heat leakage, (b) and storage time [12]

LNG pricing based on long-term contracts in the Asian market has historically taken the form of an "S-curve" based on the formula (6):

$$P(\text{LNG}) = ax + b, \text{ (USD per MMBtu)}, \quad (6)$$

Where  $a$  is slope of the price curve (including unit conversion of USD per unit) "Barrels to USD to MMBtu",  $x$  is Japanese Customs Cleared, and  $b$  is constant. Because this study aims to use LNG ISO Tank economically, specific information regarding the contract value is needed as a simulation analysis based on a long-term plan if this program is continued for a very long period of time, and the number of LNG enthusiasts is quite large. The discount rate is determined based on the entity's cost of debt and The proportion of debt and equity utilized is taken into account while evaluating equity. WACC [Weighted Average Cost of Capital] is the term used to describe this equation (7) [13].

$$\text{WACC} = (E / V * Ke) + (D / V * Kd (1-tc)), \quad (7)$$

Where  $Ke$  is equity-funded enterprises as a percentage of total firms,  $Kd$  is cost of debt,  $tc$  is corporate tax rate,  $E/V$  is equity-funded enterprises as a percentage of total firms, and  $D/V$  is proportion of companies funded by debt.

" $Ke$ " referred to the rate of return required by investors to undertake an equity investment. For the hypothetical investor, the Capital Asset Pricing Model (CAPM) was utilized to calculate  $Ke$ . The CAPM measures the minimal rate of return a firm must achieve on its funded capital share in order to maintain the market price of its shares at the same level. The CAPM is the most frequently acknowledged and utilized method for calculating equity capital costs [13].

Under CAPM,  $Ke$  is determined using the following formula (8):

$$Ke = Rf + \beta (Rm - Rf) + \alpha \quad (8)$$

Where  $Rf$  is risk-free rate of return,  $Rm$  is expected return on market portfolio,  $Rf - Rm$  is equity market risk premium (EMRP),  $\alpha$  is risk premium for a particular company, and  $\beta$  is systematic risk of a stock. The risk-free rate ( $Rf$ ) compensates investors for the

time value of money as well as the predicted rate of inflation over the investment period. Long-term government bonds (10 years), a commonly used and acknowledged benchmark for risk-free exchange rates in Australia, are frequently employed as a proxy for  $R_f$  [13]. The following would explain the assumptions used in LNG analysis and gas to liquid (GTL) analysis in Table 4.

**Table 4.** Assumptions used in LNG and GTL analysis [14]

No	Caetegory	Assumption uses in	
		LNG Analysis	GTL Analysis
1	Assessment start date	1/1/2012	1/1/2012
2	Scenario selection	4 MPa	2.9 MPa
3	Start production	31/12/2020	31/12/2020
4	Economic life project	30 years	20 years
5	Determination basis	Profil base	Profil base
6	Rate of return	10%	10%
7	Dry gas content	100%	100%

In terms of profit, it was apparent that LNG could produce more gas volumes than GTL, and the LNG project's duration was longer than GTL's. LNG was thus more profitable than GTL.

## CONCLUSIONS

By doing this research, LNG could be applied on a mass scale because based on existing secondary data, it had a project value of 30 years of economic life. This value was greater than the GTL which only has a project value of 20 years of economic life. This means that the longer the project value, the more feasible, it was to apply it on a mass scale. The type II tank showed not large heat spread, so it was safe as a container for LNG, and it was feasible if this type of tank was ISO licensed because the heat flux was not so large compared to other tanks in general. With the acquisition of 4 million tons of gas per year, this value was greater than the value of GTL which only got 2.9 million tons of gas per year. Thus, from a broad economic perspective, LNG was quite feasible as economical fuel.

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