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https://doi.org/10.5109/2321007

出版情報：Evergreen. 6 (2), pp.134-142, 2019-06. 九州大学グリーンテクノロジー研究教育センター
バージョン：

Analysis of ISO-Tank Wall Physical Exergy Characteristic – Case Study of LNG Boil-off Rate from Retrofitted Dual Fuel Engine Conversion

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(Received March 8, 2019; accepted March 26, 2019)

Ministry of Transportation of the Republic of Indonesia has conducted a feasibility study for conversion plans with the use of 60% LNG fuel on its 3200 DWT passenger ship using LNG ISO-tank type T75 size 20 feet (1 TEU), but only limited to economical study. To verify that the conversion plan is really profitable, analysis of physical exergy characteristics i.e. the rate of exergy transfer and destruction through tank wall due to heat transfer, boil-off rate and boil-off gas from stored LNG is conducted by a closed system exergy balance approach with specified shipping conditions parameters, using the empirical equations of the literature and physical model of the three tank options offered, designed using COMSOL Multiphysics 5.1. The results show a positive correlation between exergy destruction rate with BOR and BOG values, depending on the total thermal resistance value R_{tot} due to material variation of shell and insulation of tank wall affecting the value of heat leak on the inner and outer surface of the tank wall. Quality scale is presented to summarize the analysis parameters that can be measured by cost, i.e. the exergy cost and operating costs required by forced vaporizer to achieve the required BOR.

Keywords: dual fuel, retrofit, LNG, heat leak, physical exergy, exergy transfer. exergy destruction, boil-off gas, ISO-tank.

1. Introduction

In the case of ships using liquefied natural gas fuel, either partially or completely, the amount of Boil-off Gas (BOG) is indicated by Boil-off Rate (BOR) depending on the specification of the existing storage system and environment [1]. The process of evaporation of LNG into gas phase indicates the existence of ongoing thermodynamic process, it is necessary to find relation with characteristic of exergy movement through wall of ISO-tank tank in question [2]. In general, a ship which used gas evaporation of LNG specially designed with highly insulated storage tanks, this matter is used to avoid evaporation of the valuable cargo during a transportation [3,4]. The storage of evaporation gas from LNG commonly use of ISO-Tank, some portion will vaporize on the liquid surface of the cargo, producing boil-off gas (BOG) [5]. The amount of BOG will increase when the pressure level of the storage tanks and thus the mechanical stress of the structure [6].

Simply put, the liquefied natural gas stored in ISO-tanks has exergy accompanying heat transfer but does not yet have exergy accompanying work because it has not been used [7]. Given that exergy or available energy can be lost or destroyed so that it cannot be used, it can be deduced that the greater the BOR will be the greater the possibility of a large energy loss [8]. In order to remove or utilize the BOG from the ISO-tank, the main engine of the ship with steam turbine propulsion systems have been widely used [9, 10, 11]. The unused BOG is burned in boilers to produce steam, which is fed to steam turbine system and turbo generators then, in the end, will supply propulsion and electric power [12, 13]. In the other hand, the ship propulsion with steam turbine system has a lower thermal efficiency compared to heavy fuel oil (HFO) diesel engines, which is the main propulsion system of common cargo ships [14, 15]. In addition, steam turbine system has disadvantages in the need high improved insulation technologies for ISO-tanks and a large amount of carbon dioxide in the exhaust gas from the boiler. Thus, the selection of the insulation type of ISO-tanks for the BOG is important issues in the use of Dual Fuel Engine Conversion.

Ministry of Transportation of the Republic of Indonesia via X Company has selected one type of ISO-tank type T75 as LNG storage, and also 2 other T75 tank options to consider, which will then be ordered if it is declared more effective and efficient, both technically and economically in the long run. The exergy analysis in the LNG fuel storage tank on board is done to provide a choice of specification / improvement of the optimal system or component so as to minimize matters including the number of BOGs, the high BOR and the occurrence of exergy destruction due to available energy through the tank wall is wasted into energy [16]. The purpose of this research is to study the exergy accompanying heat transfer characteristics through the tank wall of the three ISO-tank tank options on plate material parameters and insulation using physical model in *COMSOL Multiphysics 5.1 Academic Server License* software [17]. Then determine the value of BOR and the number of BOG on the three ISO-tank tank options and provide the exterior and BOR analysis results of the three tank options along with their relationship, the tank laying analysis and provide recommended tank selection suggestions later in the form of a quality scale matrix, which will then serve as a basis for assessing the feasibility of a dual-fuel on ships using ISO-tank as an LNG fuel storage. The analysis consists of the rate of exergy transfer and destruction through tank wall due to heat transfer, boil-off rate and boil-off gas from stored LNG.

2. Experimental Details

2.1 Review on Economic Feasibility Study

The economic context cannot be excluded from the company's business plan, so the conversion impact is economically desirable to discuss, primarily to compare the results of the existing feasibility studies with academic studies, especially in this study which examines exergy performance and BOR BOG values from LNG storage tanks. **Tables 1 and 2** form the basis for economic calculations that have been implemented by X Company, then furthermore, the results of the exergy performance assessment and BOR BOG will be used to verify whether the plan is really profitable or not. However, going back to the original purpose of X Company initiated this idea of converting a ship engine in order to use dual fuel for savings while lowering the impact of emissions on the environment, of course, these parameters are the least profitable. Required tank option is not the cheapest price, but with determining optimum price is expected to get optimum performance as well, especially the performance of the tank from the context of heat leaks that occur and the suitability of the amount of BOG produced throughout the tank with a substitution plan ratio of 40-60 for HSD and LNG [18].

Table 1: Routes and ship fuel consumption (MoT)

Route	Sail hour		Berth hour		Mileage	
Tg. Priok - Tg. Perak	23	hour	24	hour	396	Nmi
Tg. Perak - Makassar	26	hour	5	hour	458	Nmi
Makassar - Tg. Perak	25	hour	6	hour	458	Nmi
Tg. Perak - Tg. Priok	23	hour	3	hour	396	Nmi
Total 1 Voyage	97	hour	38	hour	1708	Nmi
Consumption	1968.68	liter/h	332.67	liter/h	17.61	$V_{s,avg}$
Total 1 Voyage	190961.96	liter	12641.46	liter	203603.42	liter
					168990.8386	kg

Table 2: Price matrix, density and LHV of fuel (reprocessed) (MoT)

HSD	Value	Unit	LNG	Value	Unit
Density, ρ	830 0.83	kg/m^3 kg/L	ρ	450 0.45 24.02 18.73438801	kg/m^3 kg/L MMBtu/m^3 kg/MMBtu
Price (Pertamina IFM per 30 April 2018)	Rp10,700.00 Rp12,891.57	per liter per kg	Price (PGN per 30 April 2018)	$9.95 Rp137,817.45	per MMBtu per MMBtu
LHV	10500 43932	kcal/kg kJ/kg	LHV	12000 50208	kcal/kg kJ/kg

2.2 Governing Equations of Simulation

The rate of displacement and destruction of the physical exergy in a steady state can be calculated based on energy transfer due to heat transfer alone, due to the absence of energy converted into work, such that $Q_{in} = Q_{out}$. The transfer of exergy along with heat (exergy transfer accompanying heat transfer) on the inner surface can be evaluated by equation 1 as follows:

$$Exq,1 = \left[1 - \frac{T0}{T1}\right] Q/A \quad (1)$$

Then for the value of exergy displacement along with the transfer of heat on the outer surface can be evaluated by equation 2 as follows:

$$Exq,2 = \left[1 - \frac{T0}{T2}\right] Q/A \quad (2)$$

Furthermore, the value of exergy destruction can be evaluated from the difference between equation 1 (inner surface exergy displacement) and 2 (external exergy displacement) written into:

$$Ex,d = \frac{Exq,1}{A} - \frac{Exq,2}{A} \quad (3)$$

Exergy efficiency can be evaluated by using equations 1 to 3, where the exergetic efficiency is expressed by

$$\eta Ex = \frac{Ex,out}{Ex,in} \quad (4)$$

A simple approach to modeling heat leak calculations on a cylindrical tank with a torispheroidal dome cap can be performed with an ordinary cylindrical shell model with the determination of the shell layers and insulation as shown in **Fig. 1**, due to similar cross-section shape and the difference in both not much different as described in the study by Rossios [19]. This modeling utilizes the combined equation between the heat conduction through the composite wall and the heat conduction through the cylindrical wall with the ambient air ambient and the fluid temperature within the specified cylinder [20].

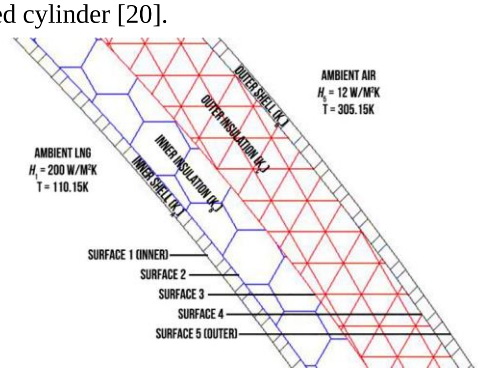

Fig. 1: Temperature distribution on cylindrical composite walls.

The calculation of the one-dimensional steady state heat transfer rate for layered cylinders taking into account the ambient fluid inside and around this cylinder can be described as follows:

$$q_r = \frac{T_{\infty,1} - T_{\infty,4}}{\frac{1}{2\pi r_1 L h_1} + \frac{\ln(r_2/r_1)}{2\pi k_A L} + \frac{\ln(r_3/r_2)}{2\pi k_B L} + \frac{\ln(r_4/r_3)}{2\pi k_C L} + \frac{1}{2\pi r_4 L h_4}} \quad (5)$$

which can be written also by using the overall heat transfer coefficient *U* as follows:

$$q_r = \frac{T_{\infty,1} - T_{\infty,4}}{R_{tot}} = UA(T_{\infty,1} - T_{\infty,4}) \quad (6)$$

where R_{tot} is the total thermal resistance value. If *U* is defined it corresponds to the inner width, $A_1 = 2\pi r_1 L$, equations 5 and 6 can be synchronized to get:

$$U_1 = \frac{1}{\frac{1}{h_1} + \frac{r_1}{k_A}\ln\frac{r_2}{r_1} + \frac{r_1}{k_B}\ln\frac{r_3}{r_2} + \frac{r_1}{k_C}\ln\frac{r_4}{r_3} + \frac{r_1}{r_4}\frac{1}{h_4}} \quad (7)$$

This definition can be changed, and *U* values can also be found from A_4 or other middle area. Note that:

$$U_1A_1 = U_2A_2 = U_3A_3 = U_4A_4 = (\Sigma R_t)^{-1} \quad (8)$$

and the specific form of U_2, U_3 dan U_4 can be derived from equations 7 and 8. The rate of heat transfer through each layer has a constant value as thick as that wall, as stated in the equation:

$$\dot{Q} = \frac{\Delta T(i-j)}{Rij} \quad (W) \quad (9)$$

with ΔT_{i-j} is the difference between the temperatures on surface *i* and surface *j* on the material layer *ij*, and the thermal value of the conductive thermal resistance R_{cond} obtained from the thermal conductivity value *k*. For cylindrical composite walls, the equations used are as follows:

$$Rcond, cyl = \frac{\ln(\frac{rj}{ri})}{2\pi Lk} \quad (K/W) \quad (10)$$

with the natural logarithm value of the ratio of *r* (radius) from the center of the cylinder to the outer surface i to the inner surface j, provided that $r_i > r_j$, *L* is the length of the cylinder and *k* specific for the material being passed. If heat transfer occurs between ambient air contacting the first surface of a composite wall, or from the final surface of a wall, the convective thermal resistance R_{conv} can be calculated by the following equation:

Table 3: **ISO-tank options comparation matrix**

Option	**Supplier**	**ISO Size**	**Inner Diameter**	**Outer Diameter**	**Shell**			
					Material	**Inner thickness**	**Outer thickness**	**Thermal conductivity @300K**
A	Trencor	20 ft	2200 mm	2320 mm	AISI 304	5 mm	5 mm	14.9 W/m.K
B	Odyssey			2424 mm	AISI 316L	6 mm	6 mm	13.4 W/m.K
C	Taizhou			2322 mm	Titanium	8 mm	8 mm	21.9 W/m.K
Option	**Supplier**	**Net capacity**	**Insulation**					
			First layer			**Second layer**		
			Type	**Thickness**	**Thermal conductivity**	**Type**	**Thickness**	**Thermal conductivity**
A	Trencor	21000 m3	Polyurethane	20 mm	26 mW/m.K	Rockwool	30 mm	35 mW/m.K
B	Odyssey		Glasswool	50 mm	35 mW/m.K	Rockwool	50 mm	35 mW/m.K
C	Taizhou		Polystyrene	20 mm	33 mW/m.K	GFRP	25 mm	36 mW/m.K

$$Rconv, cyl = \frac{1}{2\pi rLh} \quad (K/W) \tag{11}$$

The thermal resistance works on a principle more or less the same as the electrical resistance, in series as in the cylindrical composite wall of **Fig.** 1 before, the *R* value is

cumulative, with R_{total} being the divisor of equation 5 above. Knowing the value of thermal resistance for each layer (incremental) and subtotal between layers (cumulative) will be useful to calculate the temperature on each layer surface numerically if the known temperature value is only external and internal ambient temperature [19]. Boil-off rate (BOR) or gas evaporation rate and percent boil-off gas (BOG) per day in an LNG tank modeling can be calculated by the following equation [21]:

$$BOR\ (\frac{kg}{s}) = \frac{Q\ (W)}{\Delta H\ (\frac{J}{kg})} \tag{12}$$

with $\dot{Q}$ being the heat value of the system (heat leak) and ΔH representing the latent heat of vaporization, i.e. 5.1×10^5 J / kg. Then the %BOG value is calculated by the equation

$$\%BOG\ per\ hari = \frac{BOR\ \left(\frac{kg}{s}\right) x\ 3600 \frac{s}{h}\ x\ 24 \frac{h}{d}\ x\ 100\%}{VLNG\ (m3)\ x\ \rho LNG\ (\frac{kg}{m3})} \tag{13}$$

2.3 Geometrical Dimensions

The work of this paper will require some data before then the data can be processed and analyzed, with the main data provided by Ministry of Transportation and supporting data will be completed based on literature reference. The vessel to be analyzed is an Inter-island Ship Vessel owned by Ministry of Transportation, which serves the Tanjung Priok - Makassar route, a total distance of 1708 nautical miles and the total day of the screen and the day of the day is 5,625 days, the average speed is 17.6 knots. The study was a study of shell material variation and ISO-tank insulation on physical exergy characteristics and Boil-Off Rate LNG load value. There are 3 variations of tank options provided by X Company, with the specifications shown in **Table 3**.

Ship KM. C is planned to use a combination of LNG and HSD fuels with a ratio of 60-40, h = 200 W/m^{2}K with fuel specifications based on General Services Laboratory references [22] as follows:

Origin	: Indonesia – Arun
Price rate	: US$ 9.95 per MMBtu equivalent Rp137.817,45 per 30 April 2018
LHV	: 50208 kJ/kg
Density	: 450 kg/m^3 equivalent 24.02 MMBtu/m^3

Referring to Rossios, the tank will be modeled in the form of shell layers and cylinder insulation to facilitate calculations because of the same cross-sectional shape as the tank shape (i.e. the cylinder with the dome of the torispherical dome at both ends), and the difference in volume not much different. Modeling is done manually using formulas from literature references and journals shown in Fig. 2, later to be compared with modeling using *COMSOL Multiphysics 5.1* software.

(a) (b)

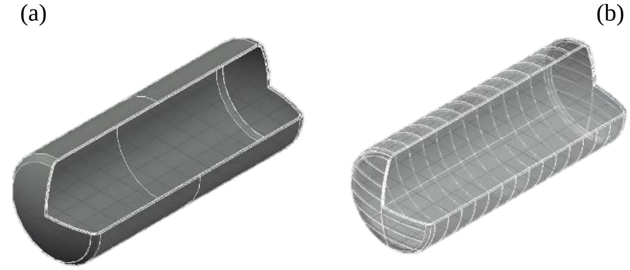

Fig. 2. 3-dimensional solid model (a) and mesh model (b) of ISO-tank.

2.4 Modeling and Simulation

In this analysis there will be exchanged rate of heat exergy Ex_q rate, exergy destruction rate Ex_d and ηEx exergetic efficiency. Similar to the modeling stage, the exergy analysis will be performed with manual calculations based on the formulas of literature references and journals, then will be compared with hot flux analysis using *COMSOL Multiphysics 5.1* software with the steps briefly shown in **Fig. 3 and 4**. Modeling for each tank is done by selecting the Heat Transfer in Solids module with the stationary study type, then constructing a model of cylindrical shell layers with caps for each material in accordance with the specifications.

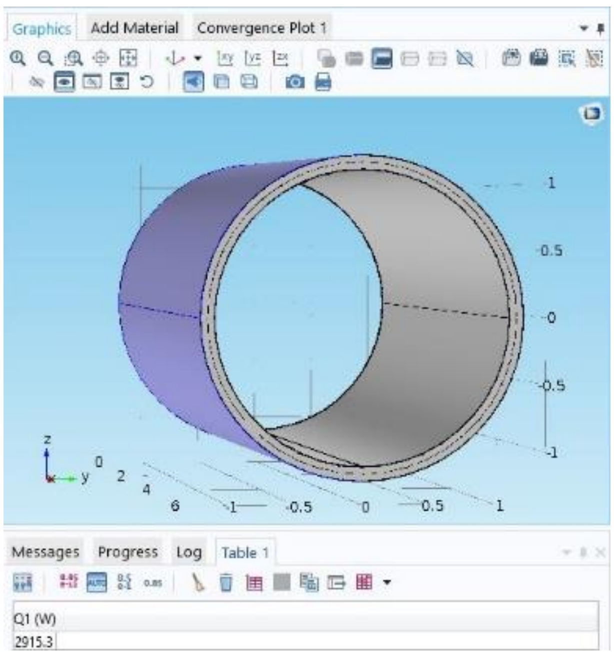

Fig. 3. Construction of cylinder layer on COMSOL 5.1.

Then the heat flux value from the outer wall and the inner wall of the tank is calculated using the surface average, and the temperature distribution in each layer is calculated using the line average. From this model we will also obtain a heat map due to heat transfer from outside the tank (ambient air) into the tank (LNG assumed ambient) through each layer of the tank wall. Data obtained from COMSOL can then be exported and then processed by the equations of the literature to obtain exergy displacement values, exergy efficiency and BOR characteristics as well as BOG for each type of tank modeled.

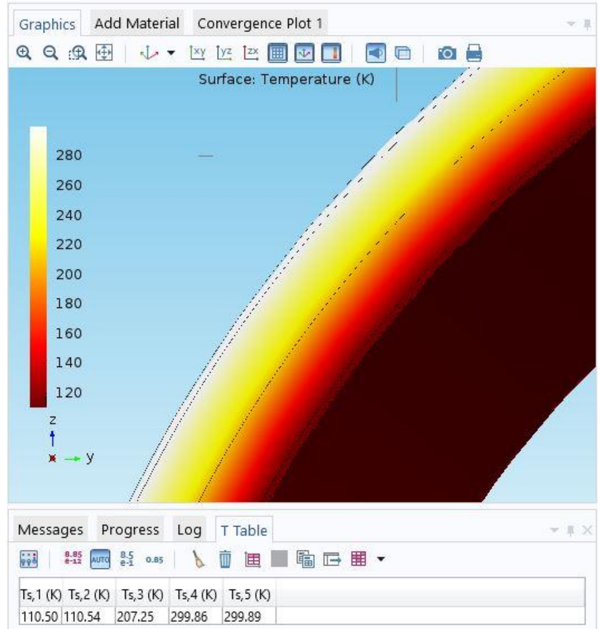

Fig. 4: Calculation of temperature distribution and heat leak through the wall on COMSOL 5.1.

2.5 Validation Results

As far as the authors of this paper concerned, there are no recent papers with more or less similar topics to refer to, and with that being said the validation is conducted between numerical and software calculations on T and $\dot{Q}$ values (which are shown in **Table 4** on the following section) to determine the relative error of both parameters. The error percentage of each parameter for each option are as follows:

Option A (Trencor)

- $\dot{Q}$ value = **0.183%**
- Average $Ts_{,5}$ to $Ts_{,1}$ value = **0.115%**

Option B (Odyssey)

- $\dot{Q}$ value = **0.043%**
- Average $Ts_{,5}$ to $Ts_{,1}$ value = **0.011%**

Option C (Taizhou)

- $\dot{Q}$ value = **0.063%**
- Average $Ts_{,5}$ to $Ts_{,1}$ value = **0.034%**

The relatively small error percentage as a result of simulation's validation implied that both of the numerical and software calculations are based on the same equations with small margin of error.

3. Results & Discussions

To find the value of temperature on each surface numerically, firstly used equations 10 and 11 to find the value of thermal resistance of each layer on the tank wall with the arrangement in **Fig. 1**. Furthermore, manual calculation of $\dot{Q}$ based on the formula derived from the literature, especially equations 6 to 8, and then comparable with the modeling results using *COMSOL Multiphysics 5.1* software. From the results of modeling using the software will get the outer and inner surface $\dot{Q}$ value, along with surface temperatures on each surface of the tank wall layers. Using the thermal resistance value, the temperature at each layer surface is also numerically searched using equation 9. The data obtained will be used to calculate the displacement and destruction of exergy and its efficiency, described in **Table 4** for each tank.

Table 4: Option A, B and C's T and $\dot{Q}$ values

Option A (Trencor)	Numerical	Software
$\dot{Q}$	4885.42 W	4894.39 W
$T_{\infty,5}$ (ambient air)	305.15K	305.15K
T_{s5} (surface 5)	295.93K	295.85K
T_{s4} (surface 4)	295.89K	295.81K
T_{s3} (surface 3)	199.38K	200.31K
T_{s2} (surface 2)	110.83K	110.81K
T_{s1} (surface 1)	110.77K	110.74K
$T_{\infty,1}$ (ambient LNG)	110.15K	110.15K
Option B (Odyssey)	**Numerical**	**Software**
$\dot{Q}$	2913.32 W	2914.56 W
$T_{\infty,5}$ (ambient air)	305.15K	305.15K
T_{s5} (surface 5)	299.89K	299.89K
T_{s4} (surface 4)	299.86K	299.86K
T_{s3} (surface 3)	207.26K	207.25K
T_{s2} (surface 2)	110.57K	110.54K
T_{s1} (surface 1)	110.52K	110.50K
$T_{\infty,1}$ (ambient LNG)	110.15K	110.15K
Option C (Taizhou)	**Numerical**	**Software**
$\dot{Q}$	6042.29 W	6046.09 W
$T_{\infty,5}$ (ambient air)	305.15K	305.15K
T_{s5} (surface 5)	293.76K	293.75K
T_{s4} (surface 4)	293.71K	293.70K
T_{s3} (surface 3)	197.04K	197.00K
T_{s2} (surface 2)	110.99K	110.91K
T_{s1} (surface 1)	110.95K	110.87K
$T_{\infty,1}$ (ambient LNG)	110.15K	110.15K

The characteristics of the temperature distribution line in **Fig. 5** indicate conformity with the literature, where the temperature appears to drop drastically as it passes through the insulation. This is a temperature drop (temperature drop) calculated using equation 9 with the value $\dot{Q}$ which has been obtained previously (which is the same value on each surface) and the thermal resistance value of each layer to be determined its surface temperature values.

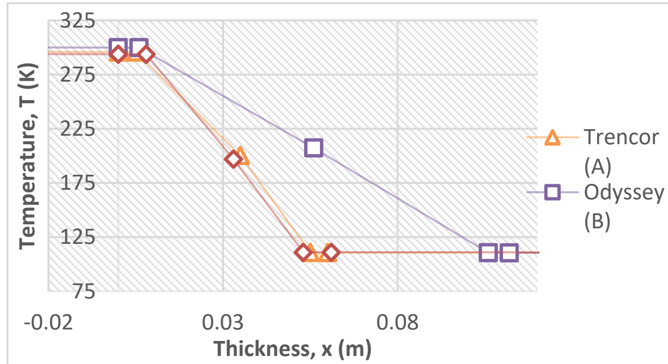

Fig. 5: Temperature distribution diagram on the tank wall.

Furthermore, the T and $\dot{Q}$ values obtained above will be processed using equations 1 to 4 to obtain exergy transfer rate values in conjunction with the heat transfer (Ex_q), destruction and exergetic efficiency of heat transfer from the three designed tank models [23]. The value of $\dot{Q}$ to be used from each tank is the largest, i.e. $\dot{Q}_{software}$, outlined in **Table 5**.

Table 5: Transfer rate, destruction and exergy efficiency for each ISO-tank option.

Option A (Trencor)		
$Ex_{q,in}$	8592.64	W
$Ex_{q,out}$	8438.79	W
Ex_d	153.85	W
ηEx	98.21%	
Option B (Odyssey)		
$Ex_{q,in}$	5134.27	W
$Ex_{q,out}$	5083.12	W
Ex_d	51.15	W
ηEx	99.00%	
Option C (Taizhou)		
$Ex_{q,in}$	10594.42	W
$Ex_{q,out}$	10359.81	W
Ex_d	234.61	W
ηEx	97.79%	

Table 6: The value of BOR, BOG and the additional percentage required for each tank option.

Option A (TRENCOR)		
Net volume	21	m^3
$\dot{Q}$	4894.393	W
ΔH, vapor latent heat (IGU)	510000	J/kg
pLNG	450	kg/m^3
BOR per tank unit	0.00960	kg/s
Required addition	49.40%	($\dot{m}_{LNG,60}$)
BOG	8.77%	per day
Option B (ODYSSEY)		
Net volume	21	m^3
$\dot{Q}$	2914.565	W
ΔH, vapor latent heat (IGU)	510000	J/kg
pLNG	450	kg/m^3
BOR per tank unit	0.00572	kg/s
Required addition	69.87%	($\dot{m}_{LNG,60}$)
BOG	5.22%	per day
Option C (TAIZHOU)		
Net volume	21	m^3
$\dot{Q}$	6046.092	W
ΔH, vapor latent heat (IGU)	510000	J/kg
pLNG	450	kg/m^3
BOR per tank unit	0.01186	kg/s
Required addition	37.49%	($\dot{m}_{LNG,60}$)
BOG	10.84%	per day

In **Table 6** we calculated the specific BOR and BOG values for each tank using equations 12 and 13, and the BOR value in kg/s obtained from each tank multiplied by the number of tanks used in accordance with the feasibility study data of Ministry of Transportation of the Republic of Indonesia, i.e. 11 ISO-tank tanks, to determine the natural BOR produced by the environmental conditions and how big the difference with the BOR required to achieve substitution of 60% (0.209 kg/s).

The additional value required is intended as an addition to the flow rate of the converted gas phase LNG mass to meet the fuel substitution requirements of the option tanks A, B and C will require forced vaporizer to evaporate additional gas ($\dot{m}_{vaporizer}$) with a certain percentage against $\dot{m}_{LNG,60}$ at a maximum of 0.209 kg / s, i.e. 49.40% (0.103 kg), 69.87% (0.146 kg) and 37.49% (0.078 kg) per second respectively, for a total of 1 voids, an additional LNG vapor total of 50089.75 kg, 70843.01 kg and 38017.24 kg of each tank option to meet the mode of fuel HSD-LNG ratio of 40-60, and the need for additional heat for evaporation can be calculated by multiplying the value $\dot{m}_{vaporizer}$ with the latent heat value ΔH as shown in **Table 7**.

Table 7: Additional flow rate of LNG vapor and vaporizer heat required.

Tank option	$\dot{m}_{vaporizer}$	**Total 1 *voyage***	$\dot{Q}_{vaporizer}$
A. Trencor	0.10307 kg/s	50089.7 kg	52.56 kW
B. Odyssey	0.14577 kg/s	70843 kg	74.34 kW
C. Taizhou	0.07822 kg/s	38017.2 kg	39.90 kW

The data obtained for each tank option from this analysis and also the previous analysis can be compiled into a matrix of comparison of each parameter and its value for subsequent interpretation of the relationship between one parameter to another as described in **Table 8**.

Table 8: Matrix comparison of tank analysis parameters.

Tank option	R_{tot} (K/W)	$\dot{Q}$ (W)	Ex_d (W)	ηEx_q (%)	**%BOG per day**	$\dot{Q}_{vaporizer}$ (kW)
A. Trencor	0.0399065	4894.39	153.8460	98.21%	8.77%	52.56
B. Odyssey	0.0669249	2914.56	51.1532	99.00%	5.22%	74.34
C. Taizhou	0.0322595	6046.09	234.6119	97.79%	10.84%	39.90

From **Table 8**, there is a tendency that the smaller *total thermal resistance* R_{tot} will have an impact on the increase of *heat leak* $\dot{Q}$, the destruction rate of heat exergy through the tank wall Ex_d, the percentage of boil-off gas formed per day and the additional heat required from the forced vaporizer to produce an additional steam flow rate of LNG that can meet the fuel substitution requirement with LNG by 60%, but the exergetic efficiency of ηEx_q will decrease further. This explains the effect of shell material variation and the insulation used on the tank wall, that if the quality of the material in this context is measured by the thermal conductivity value *k*, then the material with the least thermal conductivity value k gives the hot dampening quality of the best tank with the greatest exergetic efficiency which means the exergy being destroyed or wasted into the environment is getting smaller [24].

The tank quality scale will be based on data and analysis of the results obtained, to facilitate the presentation of data and processes to further consider which tanks will be selected. The quality scale is based on measurable values in **Table 9**, i.e. the exergetic efficiency parameters measured in the power loss due to destruction of exergy in kW and power due to the need for additional heat by the forced vaporizer to increase the gas vapor mass flow rate in kW, with exergy cost of US $ 0.08 / kWh and the foreign exchange rate used is Rp13,851, - per US dollar as of April

30, 2018 and the total of 1 voyage trip has an interval of 135 hours [25].

Exergy cost is the cost of loss due to the rate of destruction of exergy occurring during LNG stored in the tank, obtained from the amount of exergy destroyed in each tank, multiplied by the total number of tanks used, the total shipping hours and the exergy cost per kWh, due to destruction exergy occurs simultaneously for each tank transported on board. While the cost of $\dot{Q}_{\text{vaporizer}}$ is already the total power requirement for the additional vaporization heat of the total tank amount used to meet the LNG substitution of $\dot{m}_{\text{LNG,60}}$ by 0.209 kg / s, multiplied by the total shipping hours and the cost per kWh.

Table 9: Matrix of tank quality scale in additional cost per voyage.

Option	***Exergy cost* for 11 tanks**					
	kW	kWh	Cost			
Trencor	1.69	228.46	$	18.28	Rp	253,153.39
Odyssey	0.56	75.96	$	6.08	Rp	84,172.56
Taizhou	2.58	348.40	$	27.87	Rp	386,053.67
Option	**Cost of $\dot{Q}_{\text{vaporizer}}$**					
	kW	kWh	Cost			
Trencor	52.56	7096.05	$	567.68	Rp	7,862,988.45
Odyssey	74.34	10036.09	$	802.89	Rp	11,120,793.81
Taizhou	39.89	5385.78	$	430.86	Rp	5,967,869.81

4. Conclusions & Recommendations

The analysis of this study shows that the physical exergy characteristics of the LNG storage tank (in this context is the T75 ISO-tank type) and the gas evaporation rate or BOR can be parameters to determine the thermodynamic performance of the tank, determined by empirical equations of literature and modeling physical use of software has been comparable with feasibility study undertaken by Ministry of Transportation of the Republic of Indonesia to verify the results of the study whether the options given in the realization of this plan are really feasible to work on and can generate profits. The conclusions obtained based on modeling and analysis of this research are as follows:

- **The smaller the value will affect greater value of heat leak through the tank wall and the greater the value of exergy that is removed and destroyed.** Amount of exergy physically destroyed from exergy displacement together with heat transfer from each tank (a) Trencor, (b) Odyssey and (c) Taizhou is 153.8460 W, 51.1532 W and 234.6119 W.
- Exergetic efficiency is a characteristic that shows how efficiently a system is to keep exergy or energy available for use in order to remain usable (how much exergy is wasted due to differences in system temperature and environment). **The smaller the value of R_{tot} the better the thermal insulation capability of a system such that the value of exergetic efficiency is greater.** The exergetic efficiency values for each tank (a), (b), and (c) are 98.21%, 99.00% and 97.79%.

Thus, it can be inferred feasible to apply and, theoretically, based on the quality scale that has been made, ISO-tank Option C (Taizhou) is the most feasible tank option to choose, due to its exergy loss the greatest loss compared to other tanks, this loss is covered with the minimum power requirement for the smallest forced vaporizer due to the total BOR value of 11 Taizhou tanks most closely related to demand (0.13041 kg/s, only 37.49% less than 0.209 kg/s).

The authors' suggestion is to consider other ISO-tank options for LNG storage, with the following criteria:

- The combination of shell and insulation material used on the tank wall has a total thermal resistance value of R_{tot} not much different from 0.0201595 K/W, which can be calculated from the thermal conductivity value of each layer of material, thereby
- For each ISO-tank unit of 21 m3, the total heat leak produced is not much different from 9672.876 W, causing
- Total BOR generated from the entire tank is not far from the requirement of gas fuel mass flow rate for dual fuel mode with a 40:60 HSD-LNG ratio of 0.209 kg/s of LNG vapor, or equal to 0.01897 kg/s BOR for each unit tank, in order to minimize the need to use forced vaporizer to meet the $\dot{m}_{\text{LNG,60}}$ required. Is suggested to simulate the effect of emission from the dual fuel engine for further investigation [26].

Acknowledgements

Authors would like to express our grandest gratitude towards Ministry of Transportation of the Republic of Indonesia and X Company, Mr. Rahmat Budiman from Pertamina Gas and Mr. Lathif Prasetyo Wibisono from Patria Maritim Perkasa, also the Department of Mechanical Engineering University of Indonesia.

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