The Study of The Use of The Liquefied Natural Gas (LNG) as The Dual Fuel For The Engine Propulsion of KM Nggapulu

Henny Pasandang Nari[1], Rudy Susanto[2], Samsul Bahri [3] and Romy Sumardiawan[4]

[1,2,3] Politeknik Ilmu Pelayaran, Makassar, Indonesia
[4] Akademi Ilmu Pelayaran AMI, Makassar, Indonesia
pasandangnari@gmail.com

Abstract. *Liquefied natural gas (LNG)* is utilized as a dual fuel source in maritime engines, where LNG serves as the primary fuel and diesel acts as the secondary fuel. In pursuit of heightened energy efficiency and diminished environmental effects within the shipping sector, LNG has surfaced as an eco-friendly alternative compared to traditional diesel. This study seeks to evaluate engine performance measured by specific fuel consumption, engine efficiency utilizing LNG and diesel, and the financial savings in ship operational expenses. This investigation was conducted on the KM ship Nggapulu. The research methodology involved a literature review that entailed recording technical specifications and operational data from the vessel as primary information along with supplementary references from books and journal publications as secondary sources. The collected vessel data includes power output, RPM, cylinder dimensions, piston stroke, and additional parameters necessary for assessing the performance of LNG and diesel engines and calculating operational cost reductions. Findings from the research reveal that the specific fuel consumption for LNG is 0.1403 kg/kWh, whereas for diesel it stands at 0.1847 kg/kWh. The efficiency of the LNG engine is recorded at 0.4646%, in contrast to diesel's 33.85%. Savings in operational costs amount to 33%. The adoption of LNG as a dual fuel results in enhanced engine efficiency and reduced specific fuel consumption, ultimately leading to lower operational expenses for the vessel.

Keywords: Dual Fuel, Engine Efficiency, Operational Cost Savings.

1 Introduction

Liquefied Natural Gas (LNG) is liquefied natural gas. The state-owned energy company, PT Pertamina, offers the use of liquefied natural gas (LNG) as fuel for the transportation and household sectors. The abundant supply in Indonesia is an advantage of LNG as an alternative fuel compared to compressed natural gas (CNG), which still has to be imported. Pertamina President Director, Karen Agustiawan, said that LNG is more environmentally friendly than petrol and diesel because it can reduce emissions by around 85 percent. In use, compared to CNG, LNG has three times the energy density

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value at the same volume and has a longer travel distance. " Using LNG as fuel can also reduce operational costs because the price of LNG is around US$ 18-20 per MMBtu. "It's much cheaper than non-subsidized diesel at IDR 9,807 per liter or the equivalent of US$31 per MMBtu," said Karen in Jakarta on Monday, 6 August 2012. The use of LNG as fuel for ships is very effective for short-distance shipping. Indonesia has many small islands, so the use of LNG as ship fuel has a positive effect on ship operating costs.

This research endeavors to address this shortfall by performing a comparative evaluation of engine performance—specifically specific fuel consumption (SFC), engine efficiency, and operational cost advantages between LNG and diesel within a dual-fuel framework. This analysis was executed on the KM Nggapulu vessel, where operational data such as engine power, rotational speed, cylinder diameter, and piston stroke were gathered and scrutinized to determine LNG's efficiency relative to diesel. This investigation builds upon earlier findings by generating more comprehensive data on the operational capabilities of LNG as a primary fuel and its financial advantages for the shipping industry.

By closing this gap, this study offers a profound insight into LNG's performance in dual-fuel marine engines, providing crucial information that can bolster the future adoption of LNG in the maritime field.

2 Literature Review

Liquefied natural gas (LNG) is natural gas (predominantly methane, CH4, with some mixture of ethane, C2H6) that has been cooled down to liquid form for ease and safety of non-pressurized storage or transport. It takes up about 1/600th the volume of natural gas in the gaseous state at standard conditions for temperature and pressure. LNG is odorless, colorless, non-toxic, and non-corrosive. Hazards include flammability after vaporization into a gaseous state, freezing, and asphyxia. The liquefaction process involves the removal of certain components, such as dust, acid gases, helium, water, and heavy hydrocarbons, which could cause difficulty downstream. The natural gas is then condensed into a liquid at close to atmospheric pressure by cooling it to approximately −162 °C (−260 °F); maximum transport pressure is set at around 25 kPa (4 psi) (gauge pressure), which is about 1.25 times atmospheric pressure at sea level.

The heating value depends on the source of gas that is used and the process that is used to liquefy the gas. The range of heating value can span ±10 to 15 percent. A typical value of the higher heating value of LNG is approximately 50 MJ/kg or 21,500 BTU/lb[1]. A typical value of the lower heating value of LNG is 45 MJ/kg or 19,350 BTU/lb.

For comparison of different fuels, the heating value may be expressed in terms of energy per volume, which is known as the energy density expressed in MJ/liter. The density of LNG is roughly 0.41 kg/liter to 0.5 kg/liter, depending on temperature, pressure, and composition[1], compared to water at 1.0 kg/liter. Using the median value of 0.45 kg/liter, the typical energy density values are 22.5 MJ/liter (based on a higher heating value) or 20.3 MJ/liter (based on a lower heating value).

The volumetric energy density of LNG is approximately 2.4 times that of compressed natural gas (CNG), which makes it economical to transport natural gas by ship in the form of LNG. The energy density of LNG is comparable to propane and ethanol but is only 60 percent that of diesel and 70 percent that of gasoline.[2]

The International Convention for the Prevention of Pollution from Ships (MARPOL), adopted by the IMO, has mandated that marine vessels shall not consume fuel (bunker fuel, diesel, etc.) with a sulfur content greater than 0.5% from the year 2020 within international waters and the coastal areas of countries adopting the same regulation. Replacement of high-sulfur bunker fuel with sulfur-free LNG is required on a major scale in the marine transport sector, as low-sulfur liquid fuels are costlier than LNG. [71] Japan is planning to use LNG as bunker fuel by 2020.[3]

Recent research has been focused on using LNG for fuel on ships other than LNG tankers. These studies show that LNG stands out in terms of emissions reduction and reduced operational costs.[4] Some economic incentives are advantageous to running an LNG propulsion system. When certain systems, such as waste heat recovery (using waste heat to do work rather than dissipate), are added to the power plant, significant savings can be observed. One study shows that an LNG engine with a WHR system saves money compared to a diesel engine with a WHR. There is a higher initial investment cost, but it is a cost-efficient method and an environmentally sound one.[5]

The use of LNG reduces sulfur oxides by nearly 100 percent, and it reduces nitrogen oxide emissions by about 85 percent. There is considerable debate as to whether the use of LNG results in reduced greenhouse gas emissions, with studies finding that methane leakage negates climate benefits.[6]

The requirements for the use of LNG fuel in shipping, particularly regarding technical and safety standards, are outlined in the International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels, commonly referred to as the IGF Code.[7]

A dual-fuel engine is designed with two fuel supply systems: one that primarily uses LNG (liquefied natural gas) and another that employs diesel fuel as a backup. In dual-fuel diesel engines, a small amount of diesel is injected to assist in igniting the gas. This configuration allows gas to serve as the primary fuel, resulting in cleaner exhaust emissions compared to traditional diesel engines. When operating on gas, the dual-fuel engine functions according to the Otto cycle, while it operates according to the Diesel cycle when using diesel fuel.

3 Methodology

The research employs a mixed-method approach, incorporating both primary and secondary data. Primary data consists of technical and operational information gathered from the ships' logbooks, while secondary data includes books and academic papers used to enhance the analysis of the primary data. The ship data encompasses various parameters such as power, rotational speed, cylinder diameter, piston stroke, and other essential metrics necessary for evaluating the performance of LNG and diesel engines.

To facilitate the analysis, data obtained from the ships, along with references from literature, journals, and online resources, are processed using Microsoft Excel to create tables and graphs illustrating the calculation results. The performance parameters calculated include indicated pressure, average effective pressure, mechanical efficiency, effective power, indicated power, hourly fuel consumption, specific fuel consumption, and overall engine efficiency. Additionally, the study involves analyzing exhaust gas emissions and calculating the volumes of LNG and diesel fuel tanks in both gas and diesel modes.

3.1 Specific Fuel Consumption

Specific fuel consumption (SFC) is an engine performance parameter that is related to the economic value of an engine because, by knowing this, you can calculate the amount of fuel needed to produce a certain amount of power in a certain time interval, which is expressed by an equation (1):

$$\mathrm{SFC} = \frac{\mathrm{F_h}}{\mathrm{N_e}} \tag{1}$$

Where SFC = specific fuel consumption (kg/kWh), F_h = hourly fuel consumption (kg/h), dan N_e = effective power (kW).

3.2 Efisiensi Mesin

Engine efficiency is the engine's ability to convert fuel heat energy into mechanical energy. Thermal efficiency can be calculated using the equation:

$$\eta_{th} = \frac{N_e}{Q_f} \tag{2}$$

Where: ηth = thermis efficiency (%), Ne = effective power (kW) dan Qf = total energy resulting from combustion (kW).

4 Result and Discussion

4.1 Result

Technical and operational data of ships at full load for the Starboard Engine are used as calculation data :.

Engine output power (N_e)	: 8520 kW
Engine speed (n)	: 428 rpm
Engine speed	: 22,4 knot
Length over all (LOA)	: 146,50 m
Average effective pressure (p_e) (solar)	: 18,8 bar

Max pressure combustion (p_z) (solar) : 152 bar

Outside air temperatur : 25^0C

Outside air pressure : 1,025 bar

Turbocharger (intake air pressure)

- Before *cooler* : 1,995 bar
- After *cooler* (p_{sup}) : 1,960 bar

Charge the air cooler

- Inlet air temperature : 166^0C
- Exit air temperature (T_{sup}) : 51^0C

Number of cylinder (i) : 8 silinder

Stroke (step) (z). : 4

Cylinder Diameter (D) : 0,58 m

Piston Stroke (L) : 0,6 m

Compression ratio (ε). : 13,15

Calorific value of diesel fuel (Q_l) : 42276 $\frac{kJ}{kg}$

Calorific value of gas fuel (Q_l) : 55206 $\frac{kJ}{kg}$

Relative Humadity (ϕ) : 60%

Table 1. Calculation Results of Engine Performance Using LNG Fuel and Diesel Fuel

Keterangan	LNG		SOLAR	
Initial Compressi Temperature (T_a)	339	^{0}K	339	^{0}K
Initial Compression Pressure (p_a)	$1,8032x10^5$	Pa	$1,8032x10^5$	Pa
Income Efficiency (η_{ch})	0,9516		0,9516	
End Compression Pressure (p_c)	$62,5364x10^5$	Pa	$62,5364x10^5$	Pa
End Compression Temperature (T_c)	894,0532	^{0}K	894,0532	^{0}K
Theoretical amount of air (L_o')			0,4946	kmol
Theoretical air volume (A_{th})	9,5238	mol		
Actual Air Requirement (L')			0,6168	kmol
Actual Air Volume (M_1)	13,3809	mol		
Number of moles of CO_2 (MCO_2)	1	mol	0,0725	kmol
Number of moles of H_2O (MH_2O)	2	mol	0,063	kmol

Number of moles of N_2 (MN_2)	9,8409	mol	0,4873	kmol
Number of moles of O_2 (MO_2)	0,6	mol	0,0256	kmol
Total number of moles (Mg) = (M_2)	13,4409	mol	0,6484	kmol
Theoretical molar coefficient of change (μ_{th})	1,0044		1,0513	
Actual molar coefficient of change (μ_{th})	1,0044		1,0513	
Mole fraction CO_2 (VCO_2)	0,0744		0,1118	
Mole fraction H_2O (VH_2O)	0,1488		0,0972	
Mole fraction N_2 (VN_2)	0,7322		0,7515	
Mole fraction O_2 (VO_2)	0,0446		0,0396	
Combustion product coefficient (A_g)	5,0322		5,0915	
Combustion product coefficient (B_g)	0,0006713		0,0006678	
Average molar heat capacity of air constant volume $(mcv)_a$	5,0938		5,0938	
Max combustion pressure (p_z)	$212 x 10^5$	Pa	$152 x 10^5$	Pa
Max combustion temperature (T_z)	1623	^0K	2481,69	^0K
Comparison of pressure rise (λ)	3,4005		2,43	
Comparison of initial expansion (ρ)	1		1,2	
Comparison of continued expansion (δ)	13,15		10,953	
End expansion pressure (p_b)	$7,4676 x 10^5$	Pa	$7,446 x 10^5$	Pa
End expansion temperature (T_b)	749,4684	^0K	1331,5744	^0K
Theoretical indicated pressure (p_{it})	$22,921 x 10^5$	Pa	$20,781 x 10^5$	Pa
Actual indicated pressure (p_i)	$22,234 x 10^5$	Pa	$20,157 x 10^5$	Pa
Mechanical efficiency (η_m)	0,85		0,93	
Average effective pressure (p_e)	$18,89 x 10^5$	Pa	$18,8 x 10^5$	Pa
Effective power (N_e)	8520	kW	8520	kW
Indication Power (N_i)	10023,7147	kW	9135,4328	kW
Fuel Consumption Indication (F_i)	0,1193	$\frac{kg}{kWh}$	0,1723	$\frac{kg}{kWh}$
Effective Fuel Consumption (F_e)	0,1403	$\frac{kg}{kWh}$	0,1847	$\frac{kg}{kWh}$
Fuel Consumption per hour (F_h)	1195,7	$\frac{kg}{h}$	1574	$\frac{kg}{h}$
Specific Fuel Consumption (SFC)	0,1403	$\frac{kg}{kWh}$	0,1847	$\frac{kg}{kWh}$
Thermal Effiency (η_{th})	46,46	%	33,87	%
Propeller power (P_p)	7242	kW	7945	kW

Calculation of Dual Fuel Fuel Consumption in Gas Mode.

a. LNG Fuel Tank Volume

1) For 2 main engines

Main engine fuel consumption :

$$= 2 \text{ x } N_{e\,ME} \text{ x } 70\% \text{ x } SFC_{LNG} \text{ x } (\frac{1}{\rho_{LNG}})$$

$= 2 \times 8520 \times 70\% \times 0{,}140 \times \frac{1}{770}$

$= 2{,}168 \frac{m^3}{h}$

For the Makassar – Baubau trip it takes 13.6 hours, so the tank volume is:

$= 2{,}168 \frac{m^3}{h} \times 13{,}6 \text{ h}$

$= 29{,}4848 \text{ m}^3$

2) For 4 *auxiliary engine*

Auxiliary engine fuel consumption :

$= 4 \times N_{e\,AE} \times 70\% \times SFC_{LNG} \times (\frac{1}{\rho_{LNG}})$

$= 4 \times 882 \times 70\% \times 0{,}140 \times \frac{1}{770}$

$= 0{,}449 \frac{m^3}{h}$

For the Makassar – Baubau trip it takes 13.6 hours, so the tank volume is:

$= 0{,}449 \frac{m^3}{h} \times 13{,}6 \text{ h}$

$= 6{,}1064 \text{ m}^3$

Total volume of LNG fuel tank :

$= 29{,}4848 + 6{,}1064 + (10\% \times 29{,}4848)$

$= 38{,}5397 \text{ m}^3 \times 770 \frac{kg}{m^3}$

$= 29675{,}5 \text{ kg} = 29{,}6755 \text{ ton}$

If the LNG price is Rp. 3,500/ltr then the total cost of LNG fuel from Makassar – Baubau is :

= 38,5397 x 1000 x Rp. 3.500

= Rp. 134.888.950,-

b. Diesel Fuel Tank Volume

1) For 2 main engines

Main engine fuel consumption :

$= 2 \times N_{e\,ME} \times 30\% \times SFC_{solar} \times (\frac{1}{\rho_{solar}})$

$= 2 \times 8520 \times 30\% \times 0{,}1847 \times \frac{1}{850}$

$= 1{,}1108 \frac{m^3}{h}$

For the Makassar – Baubau trip it takes 13.6 hours, so the tank volume is:

$= 1{,}1108 \frac{m^3}{h}$ x 13, 6 h

$= 15{,}1068\ m^3$

2) For 4 *auxiliary engine*

Auxiliary engine fuel consumption :

$= 4 \text{ x } N_{e\ AE} \text{ x } 30\% \text{ x } SFC_{solar} \text{ x } (\frac{1}{\rho_{solar}})$

$= 4 \text{ x } 882 \text{ x } 30\% \text{ x } 0{,}1847 \text{ x } \frac{1}{850}$

$= 0{,}2299 \frac{m^3}{h}$

For the Makassar – Baubau trip it takes 13.6 hours, so the tank volume is:

$= 0{,}2299 \frac{m^3}{h}$ x 13, 6 h

$= 3{,}1266\ m^3$

Total volume of diesel fuel tank:

= 15,1068 + 3,1266 + (10% x 15,1068)

$= 19{,}744\ m^3 \text{ x } 850 \frac{kg}{m^3}$

= 16782 kg = 16,782 ton

If the price of diesel is Rp. 5,500/ltr then the total cost of diesel fuel from Makassar – Baubau is:

= 19,744 x 1000 x Rp. 5.500

= Rp. 108.592.000,-

Calculation of Diesel Fuel Consumption in Diesel Mode. Calculation of diesel fuel consumption at 100% load if the journey from Makassar to Bau Bau takes 13.6 hours.

1) For 2 *main engine*s

Main engine fuel consumption :

$= 2 \text{ x } N_{e\ ME} \text{ x } SFC_{solar} \text{ x } t$

= 2 x 8520 x 0,1847 x 13,6

= 42803 kg = 42,803 ton

2) For 4 *auxiliary engine*

Auxiliary engine fuel consumption :

$= 4 \text{ x } N_{e\ AE} \text{ x } SFC_{solar} \text{ x } t$

= 4 x 882 x 0,1847 x 13,6

= 8862 kg = 8,862 ton

Total diesel fuel consumtion :

= 42,803 + 8,862 + (10% x 42,803)

= 55,945 ton

If the price of diesel is Rp. 5,500/ltr then the total cost of diesel fuel from Makassar – Baubau is:

$= 55945 \text{ x } 1000 \text{ x Rp. } 3.500 \text{ x } \frac{1}{850}$

= Rp. 361.997.058,-

The total cost in gas mode (operation) is equal to Rp. 243.480.950,-.

The total cost in diesel (operation) mode is equal to Rp. 361.997.058,-

If you use LNG fuel, there will be savings of:

$$= \frac{Rp361.997.058 - Rp.243.480.950}{Rp.361.997.058} x100\%$$

= 33%

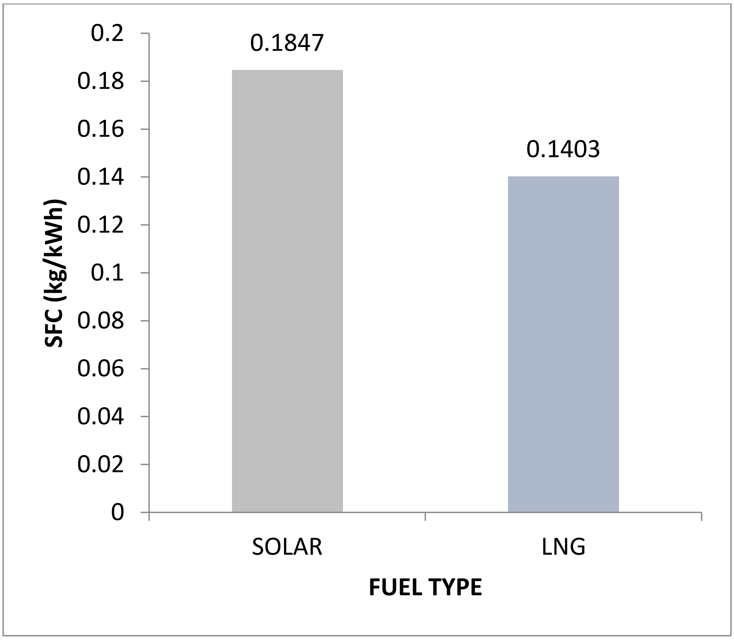

Fig. 1. Graph of the relationship between specific fuel consumption (SFC) and fuel type (Diesel Fuel and LNG) at the same power and speed

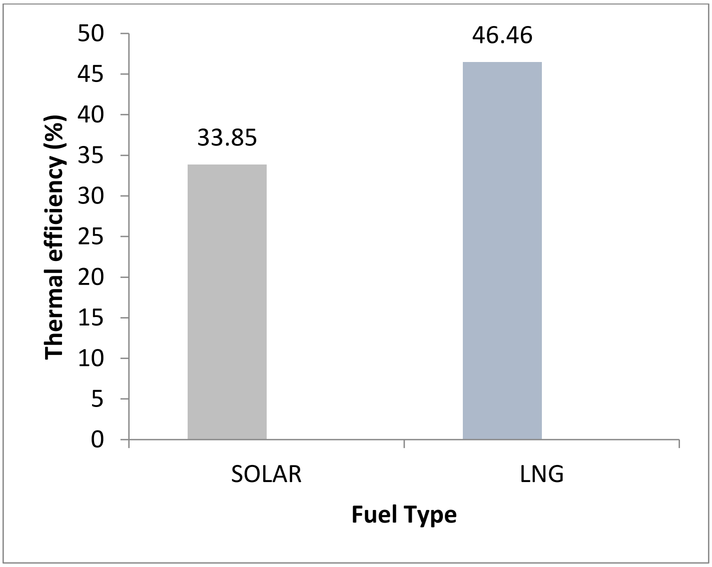

Fig. 2. Graph of the relationship between thermal efficiency (η_{th}) and fuel type (Diesel Fuel and LNG) at the same power and rotation

4.2 Discussion

This research shows that specific fuel consumption (SFC) is a parameter used as a measure of the economy of an engine. In Table 1 of the calculation results, the specific fuel consumption (SFC) value for LNG is 0.140 kg/kWh and the SFC value for diesel is 0.1847 kg/kWh at the same power and rotation. Another performance parameter that can also be used as a measure of the economy of a machine is thermal efficiency. The thermal efficiency of LNG is 46.46%, while the thermal efficiency of diesel is 33.85%. In contrast to specific fuel consumption (SFC), thermal efficiency has an inverse relationship with SFC. The higher the thermal efficiency, the more economical the fuel consumption [8]. This can be seen in Table 1. LNG fuel consumption per hour is 1195 kg, while diesel is 1574 kg per hour.

From data obtained in several Wartsila journals and the Second IMO GHG Study 2009, International Maritime Organization [9], that by using LNG fuel, engine efficiency will increase because the fuel consumption used is less than using diesel fuel. It can also be seen that if you use LNG fuel there will be a savings in operational fuel costs of 33%. It is cheaper to use LNG than diesel [10].

5 Conclusion

By using LNG fuel as the main fuel in ship propulsion engines, specific fuel consumption (SFC) will be lower, namely 0.1403 kg/kWh compared to using diesel fuel, namely 0.1847 kg/kWh. The thermal efficiency using LNG fuel is also greater, namely 46.46% compared to the thermal efficiency using diesel fuel which is only 33.85%. The higher the thermal efficiency, the more economical the fuel consumption.

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