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COMPARATIVE STUDY OF EXHAUST EMISSIONS DIESEL FUELED SHIPS AND LIQUEFIED NATURAL GAS (LNG)

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ABSTRACT

LNG can be used as an alternative fuel in the shipping industry and as ship fuel because it can reduce exhaust emissions from CO2 by 30%, NOx by 85%, and SOx by 99.9% or 100%. If using Heavy Fuel Oil (HFO), the exhaust emissions cannot be reduced or equal to 100%. NOx emission restrictions, SOx are regulated in Maritime Pollution (MARPOL) Annex VI, in the future IMO will limit SOx gas emissions in fuel. Ships that will pass through Emissions Control Areas must limit sulfur in their fuel to 0.10%. Thus, LNG as an environmentally friendly fuel can be used in the ECA area.This study aims to calculate the amount of CO2, SOx, and NOx composition that can be reduced by using LNG. The method used is a literature study by recording technical data and ship operational data as primary data and other references from books, papers, journals, internet as secondary data. The ship data contains power, rotation, cylinder diameter, piston stroke, and other data needed to calculate the amount of CO2, SOx, and NOx composition that can be reduced if using LNG.The results showed that exhaust gas emissions CO2, SOx, and NOx that can be reduced by 25.2%, 100% and 79.46%.
Keywords: LNG, diesel, exhaust emissions

1. Introduction

Liquefied Natural Gas (LNG) is natural gas which is liquefied by being cooled to -160^{0}C at a pressure of 1 atm (Nugraha, 2006). The abundant supply in the country is an advantage for LNG to be an alternative fuel compared to Compressed Natural Gas (CNG), which still has to be imported. LNG is more environmentally friendly than gasoline and diesel, because it can reduce emissions by about 85%. The main composition of natural gas consists of methane gas with the chemical formula CH_4 (Stewart et al., 2007).

LNG can be used as an alternative fuel in the shipping industry and as ship fuel because it can reduce exhaust emissions from Carbon Dioxide (CO_2) by 30%, Nitrogen Oxide (NOx) by 85%, and Sulfur Oxide (SOx) by 99.9% or 100%. If using Heavy Fuel Oil (HFO), exhaust gas emissions cannot be reduced or equal to 100% as described by Jacobs, 2011. If using LNG, there will be a decrease in NOx because the combustion temperature produced is lower than diesel (Tepimonrat et al., 2011).). NOx will be formed at high temperatures (Khovakh, 1977).
The use of LNG as fuel for ships is very effective for short-haul voyages. Indonesia has many small islands so the use of LNG as ship fuel has a positive effect on ship operating costs (Budihartono et al., 2012). The purpose of this study is to calculate the composition of CO_2, SOx and NOx when using LNG. The ship's diesel engine is a proven engine that is reliable and efficient in the use of fuel. However, one of the drawbacks of diesel engines is the presence of emissions in the exhaust gases. NOx, SOx, CO_2 and particulate emissions are the main emissions from marine diesel engines. The poor condition of air quality due to exhaust gases released by ship's diesel engines has resulted in the International Maritime Organization (IMO) setting minimum standards for NOx and SOx emissions in ANNEX VI Regulations 13 and 14.

The formulation of the problem in this research is how much CO_2, SO_x and NO_x can be reduced if using LNG ?

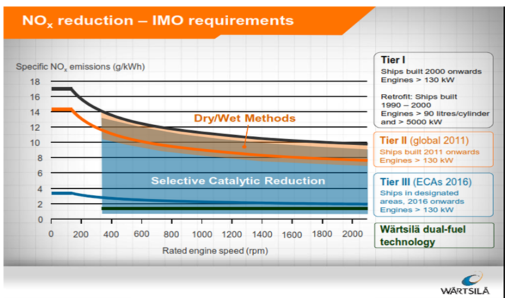

Figure 1. NOx Relationship – Engine Speed (Wartsila 20 Dual Fuel (DF) Engine Presentation, 2010)

Malahayati Maritime Journal (JuMMa)
Vol 4, No 2, Juli 2023, No, 102-105

Below is a table of indicative emissions from LNG and liquid fuel for ships – emissions related to engine output in kWh.

Table 1. Emissions related to engine output in kWh (Marintek)

Fuel Type	SOx (g/kWh)	NOx (g/kWh)	PM (g/kWh)	CO2 (g/kWh)
Residual oil 3.5% sulfur	13	9-12	1.5	580-630
Marine diesel oil, 0.5% S	2	8-11	0.25-0.5	580-630
Gasoil, 0.1% sulfur	0.4	8-11	0.15-0.25	580-630
Natural gas (LNG)	0	2	0	430-480

Table 2. Fossil Fuel Emission Rates (Pounds/Billion BTU) (Kidnay, Arthur J; William R. Parish. Fundamentals of Natural Gas Processing. CRC Press. 2006 Coal Bed Methane – From Resource to Reserves – by Bruce Atkin (GCA))

Pollutant	Natural gas	Oil	Coal
Carbon dioxide (CO2)	117,000	164,000	208,000
Carbon monoxide (CO)	40	33	208
Nitrogen Oxide (NOx)	92	448	457
Sulfur Oxide (SOx)	1	1.112	2591
Particle	7	84	2744
Mercury	0	0.007	0.016

2. Research Method

The method used in this research is literature study, namely references from books, papers, journals, internet as secondary data to calculate the amount of CO2, SOx, and NOx composition that can be derived if using LNG. To facilitate the analysis, the data obtained from references from books, papers, journals and the internet were processed using Microsoft Excel 2007 in the form of tables and graphs of the calculation results. Focus of this research is to calculate exhaust emissions.

3. Results and Discussion

Reaction equation for diesel fuel, C12 H26 **:**

$$C_{12}H_{26} + 1{,}8\left(12 + \frac{26}{4}\right)\left(O_2 + 3{,}76N_2\right) \rightarrow$$

$$12CO_2 + \left(\frac{26}{2}\right)H_2O + (1{,}8 - 1)$$

$$\left(12 + \frac{26}{4}\right)O_2 + 3{,}76(1{,}8)\left(12 + \frac{26}{4}\right)N_2$$

$$C_{12}H_{26} + 33{,}3\left(O_2 + 3{,}76N_2\right) \rightarrow$$

$$12CO_2 + 13H_2O + 14{,}8O_2 + 125{,}208N_2$$

%C = 87, %H = 12.6, %S = 0.35, %O = 0.4

Table 3. Calculation Results for Diesel Fuel

Gas	m	Mass (kg)	Mole	Volume Fraction(%) Wet gas	dry gas
CO_2	44,011	38,25	0.8691	23.9296	31.0116
O_2	31,999	39,27	1.2274	33.794	43.7966
N_2	28.013	19,77	0.7060	19.4389	25.1918
H_2O	18,015	14,94	0.8294	22.8366	
-			1,7373	100	100

Combustion Reaction Equation for LNG Fuel:

$$CH_4 + 1{,}8\left(1 + \frac{4}{4}\right)\left(O_2 + 3{,}76N_2\right) \longrightarrow$$

$$CO_2 + \frac{4}{2}H_2O + (1{,}8 - 1)(1 + \frac{4}{4})O_2 + 3{,}76(1{,}8)(1 + \frac{4}{4})N_2$$

$$CH_4 + 3{,}6\left(O_2 + 3{,}76N_2\right) \longrightarrow$$

$$CO_2 + 2H_2O + 1{,}6O_2 + 13{,}536N_2$$

% C = 74 % H = 25 % N = 0.75% O = 0.25

Malahayati Maritime Journal (JuMMa)
Vol 4, No 2, Juli 2023, No, 102-105

Table 4. Combustion Calculation Results for LNG Fuel

Gas	m	Mass (kg)	Mole Fraction(%)	Volume Wet gas	dry gas
CO_2	44,011	2,71	0.0616	4.4367	5.8058
O_2	31,999	5,06	0.0988	11.895	14.9010
N_2	28.013	23,57	0.8413	63.298	79.2932
H_2O	18,015	4,83	0.1440	20.1715	-
			1,7373	100	100

Exhaust gas emissions are gases resulting from incomplete combustion of fuel that occurs in the combustion chamber. CO2, SOx, NOx and particulate emissions are the main emissions from marine diesel engines.

a. CO2 Decrease

The number of carbon atoms in gaseous fuel molecules is less than that of oil fuel, so the CO2 formed from the combustion process is also less. From the calculation results of the exhaust gas analysis in the combustion reaction for diesel, the CO2 gas value from the combustion is 12 while in LNG it is 1. This shows that the exhaust gas emissions released by diesel are 12 times greater than LNG fuel. In table 3 and table 4 the results of the calculation of exhaust gas analysis show that in diesel the volume of CO2 (wet gas) is 23.9296% while in LNG the volume of CO2 (wet gas) is 4.6347%. In dry gas diesel, the volume of CO2 is 31.0116%, in LNG it is 5.8058%. From the comparison above, it can be seen that the reduction in CO2 gas emissions for dry gas is 25.2% when using LNG as fuel. In table 1, it can be seen the comparison of exhaust gas emission levels where there is a decrease in CO2 from the maximum value of 630 gr/kWh for diesel to 480 gr/kWh on LNG so that it can be said that there is a decrease in CO2 of 23.8%. Table 2 also shows a decrease in CO2 exhaust emissions from a value of 164,000 pounds/mBTU for oil to 117,000 pounds/mBTU for gas, so it can be said that there was a decrease in CO2 of 28.65%. (Business Development Manager of Wartsila North America Inc., Pete Jacobs). 000 pounds/mBTU in gas so that it can be said that there is a decrease in CO2 of 28.65%. (Business Development Manager of Wartsila North America Inc., Pete Jacobs). 000 pounds/mBTU in gas so that it can be said that there is a decrease in CO2 of 28.65%. (Business Development Manager of Wartsila North America Inc., Pete Jacobs).

b. SOx Decrease

In LNG fuel there is no sulfur content anymore because the sulfur has been removed when it was still natural gas so that the SOx value is 0. This can also be seen in table 1 and table 2 regarding the level of exhaust emissions, in table 1 it can be seen the comparison of emission levels exhaust gas where there is a decrease in SOx from a value of 13 gr/kWh for diesel to 0 in LNG so it can be said that there is a decrease in SOx by 100%. Table 2 also shows a decrease in SOx exhaust emissions from a value of 1,112 pounds/mBTU for oil to 1 pound/mBTU for gas, so it can be said that there was a 99.9% decrease in SOx. (Business Development Manager of Wartsila North America Inc., Pete Jacobs).

c. NOx Decrease

In the stoichiometric condition of the table, the results of the exhaust gas analysis calculation can be seen that the oxygen value is 0 which means that oxygen is not formed in the combustion products so that it can reduce the formation of NOx in the air. From table 1 and table 2 regarding the level of exhaust emissions, in table 1 it can be seen a comparison of the level of exhaust emissions where there is a decrease in NOx from a maximum value of 12 gr/kWh for diesel to 2 gr/kWh in LNG so that it can be said that there is a decrease in NOx by 83%. Table 2 also shows a decrease in exhaust gas emissions of NOx from a value of 448 pounds/mBTU for oil to 92 pounds/mBTU for gas so that it can be said that there was a decrease in NOx of 79.46%. Comparison of the reduction in exhaust emissions from diesel to LNG for NOx is 85% (Business Development Manager of Wartsila North America Inc., Pete Jacobs).

4. Conclusion

By using LNG as the main fuel, the resulting exhaust emissions can be reduced. For CO . emissions2can be reduced by 25%, SOx can be reduced to 100% because LNG does not contain Sulfur, and NOx can be reduced by 80%.

Malahayati Maritime Journal (JuMMa)
Vol 4, No 2, Juli 2023, No, 102-105

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