Marine Alternative Fuel

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Abstract

With increasing environmental regulations on ship emissions, the maritime industry is exploring alternative low-carbon fuels to replace conventional heavy fuel oil (HFO). This study analyzes and compares three potential alternative fuels - liquefied natural gas (LNG), liquefied petroleum gas (LPG), and methanol - in terms of fuel consumption, emissions, and costs

Using performance data from a two-stroke marine engine at different load conditions, the annual fuel consumption, emissions of CO2, NOx, SOx and particulate matter, and costs are modeled and compared for each fuel type

The results show that LNG provides the greatest reductions in fuel consumption and CO2 emissions, while methanol yields the highest NOx reduction. However, methanol is also the most expensive option

The results provide comparative data to help ship owners and operators evaluate the viability of transitioning to cleaner alternative marine fuels

الملخص

مع زيادة اللوائح والتشريعات البيئية على انبعاثات السفن، تستكشف صناعة الشحن البحري وقود بديل منخفض الكربون لاستبدال الوقود الثقيل التقليدي (HFO). تحلل هذه الدراسة وتقارن ثلاثة أنواع محتملة من الوقود البديل – غاز الطبيعي المسال (LNG)، غاز البترول المسال (LPG) والميثانول – من حيث استهلاك الوقود والانبعاثات والتكاليف.

باستخدام بيانات أداء محرك بحري ثنائي الأشواط في ظروف تحميل مختلفة، يتم نمذجة ومقارنة الاستهلاك السنوي للوقود وانبعاثات ثاني أكسيد الكربون وأكاسيد النيتروجين وأكاسيد الكبريت والمواد الصلبة بالنسبة لكل نوع من أنواع الوقود.

تظهر النتائج أن الغاز الطبيعي المسال يوفر أكبر انخفاض في استهلاك الوقود وانبعاثات غاز ثاني أكسيد الكربون، بينما يؤدي استخدام الميثانول إلى أقصى انخفاض في انبعاثات أكاسيد النيتروجين. ومع ذلك، فإن الميثانول هو الخيار الأكثر تكلفة.

توفر النتائج بيانات مقارنة لمساعدة أصحاب السفن والمشغلين في تقييم جدوى الانتقال إلى وقود بديل بحري أنظف.

Key Words: Marine Alternative Fuels, greenhouse gas, Marine Engine, Fuel consumption, Fuel cost

Introduction

International shipping plays an important role in global trade, moving more than 80% of the world's trade by volume. However, the large commercial fleet of more than 50,000 Ship also represents a significant source of greenhouse gas (GHG) and air pollutant emissions. International shipping is estimated to account for about 3% of all global carbon dioxide (CO2) emissions. Other harmful emissions from marine exhaust such as sulfur oxides (SOx), nitrogen oxides (NOx), and particulate matter (PM) also have significant environmental and health impacts To reduce the industry's emissions and carbon footprint, the International Maritime Organization (IMO) has introduced a series of regulations and emissions caps The global sulfur cap came into force in 2020, limiting the sulfur content of marine fuel to 0.50% from the previous 3.50%. More stringent 'emission control zones' further limit sulfur levels to 0.10%. In addition, the IMO adopted a priority in 2018 to reduce total annual GHG emissions by at least 50% by 2050 compared to 2008 levels. These more stringent regulations are driving vessel owners and operators to look for alternative, low-carbon marine fuels. Conventional heavy fuel oil (HFO) is not controlled without an exhaust gas scrubber or sulfur cleaner. Liquefied natural gas (LNG), liquefied petroleum gas (LPG), methanol, and other biofuels or synthetic fuels are seen as promising options for reducing carbon emissions as they continue to perform well The marine industry is now evaluating the viability of alternative fuels through extensive research and testing projects. The aim of this study is to compare and evaluate the three main alternatives - LPG, LNG and methanol - in terms of their benefits, costs, and overall capabilities To minimize emissions from the shipping industry and comply with IMO's emissions regulations for a sustainable future for maritime transport.

Methodology

In order to perform comparisons between different fuel types in terms of fuel consumption, emissions, and annual costs, we have selected a two-stroke marine engine. The MAN B&W 5G50ME-C9.6 engine has been selected for the study. Engine specifications, such as Low Heat value(LHV) , specific fuel consumption, power, load, etc., were obtained from the manufacturer's provided data. Fuel consumption was calculated at different Engine loads.

For emissions calculations, data published in the International Maritime Organization's GHG Study for 2020 were utilized.

When calculating fuel consumption costs, differences in prices among different regions (America, Asia, Europe) were observed. Therefore, an average rate was taken into account.

Regarding the calculation of annual engine operating hours, it was assumed that the engine operates for an average of 18 hours per day, totaling approximately 6,500 hours annually.

- **Calculations Values**

1. **Specific Fuel Consumption:** is a measure of the fuel efficiency of an engine and It represents the amount of fuel consumed by the engine per unit of power produced typically expressed in unit of (g/kWh)

The following four tables Show the specific fuel consumption (SFOC) values for each fuel type individually and at different engine loads. It can be observed that when using LPG, LNG, and Methanol, we will require pilot fuel to complete the combustion process

Table.1 HFO specific fuel consumption

Engine Load %	Power (Kw)	SFOC (g/kwh)
100	8600	168.0
75	6450	163.9
50	4300	165.4
25	2150	172.0

Table.2 LNG specific fuel consumption & specific pilot fuel consumption (diesel)

Engine Load %	Power (Kw)	SGC (g/kwh)	SPOC (g/kwh)
100	8600	143.5	2.5
75	6450	136.9	3.1
50	4300	134.4	4
25	2150	138.1	6.4

Table.3 LPG specific fuel consumption & specific pilot fuel consumption (diesel)

Engine Load %	Power (Kw)	SGC (g/kwh)	SPOC (g/kwh)
100	8600	148.2	8.4
75	6450	142.6	10.2
50	4300	141.1	13.3
25	2150	140.0	21.2

Table.4 Methanol specific fuel consumption & specific pilot fuel consumption (diesel)

Engine Load %	Power (Kw)	SGC (g/kwh)	SPOC (g/kwh)
100	8600	342.5	8.4
75	6450	329.7	10.2
50	4300	326.3	13.3
25	2150	323.6	21.2

2. **lower heating value (LHV)** the amount of heat released when a unit quantity of the fuel is completely combusted

the next table show the lower heat values of HFO, LPG, LNG, and Methanol

Table.5 LHV value of fuel

Fuel type	LHV (KJ/Kg)
HFO	42700
LPG	46000

LNG	50000
Methanol	19900

3. **CO2 Emission Factor** represents the amount of carbon dioxide emitted per unit of fuel consumption. It is typically expressed in (CO_2/ton of fuel)
4. **NOx Emission Factor:** The NOx emission factor represents the amount of nitrogen oxides emitted per unit of fuel consumption

The fallowing table show the CO2 and NOx factor for of HFO, LPG, LNG, and Methanol

Table.6 CO2 and NOx emissions factor

Fuel type	CO2 emission factor (CO2kg/kg fuel)	NOx emission factor (NOxg/kwh)
HFO	3.2	14
LPG	3.0	9
LNG	2.75	9.4
Methanol	1.5	2

5. **Fuel Price** As mentioned in the introduction, we have observed variations in fuel prices across different regions and ports. Therefore, we have taken an average of these prices. It should be noted that fuel prices are subject to fluctuations in oil prices and geopolitical conditions.

The following table shows the prices of fuel per ton in US dollar for different fuel types

Table.7 average Market price for fuel in US dollar

Fuel type	Fuel Price ($/ton)
HFO	600
LPG	610
LNG	440
Methanol	550

- **Calculations and Result**

First, we calculated the annual fuel consumption for each type of fuel at different loads. The equation used for that is:

Annual Fuel Consumption = SFOC * Power * Annual Operating Hours

The following table illustrates the annual fuel consumption for each type of fuel in ton/year:

Table.8 Annul fuel consumption for each type of fuel in ton/year

	HFO FC t/y	LPG FC t/y	LNG FC t/y	Me FC t/y
100%	9360	8273.2	7993.7	19117.8
75%	6871.5	5953.3	5743.7	13793.3
50%	4622.9	3940.9	3745.3	9111.7
25%	2403.7	2295	1928.5	4513.9

The next diagram show fuel consumption in Kg/hr for different Engin Load

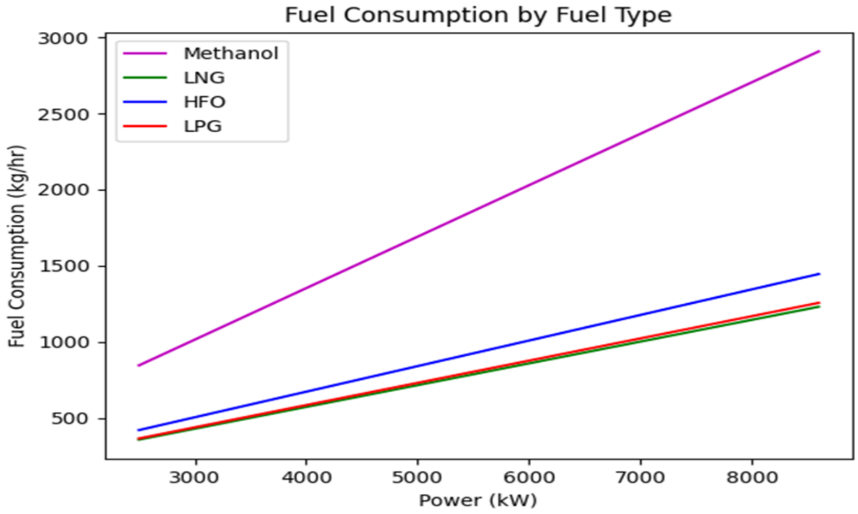

Figure.1 Fuel consumption in kilogram per hour

When analyzing the previous table and diagram, we can observe that methanol is the highest fuel types in terms of consumption, approximately double that of heavy fuel at various loads. The reason for this can be attributed to the low heat value (LHV) of methanol, as we explained in Table 5, which requires burning a larger quantity of fuel to achieve the same power output. As for LPG and LNG, they achieved low consumption compared to heavy fuel, with LNG being the most efficient type in terms of fuel consumption, followed by LPG, which is close to heavy fuel in terms of fuel consumption at low loads.

The following table illustrates the Annul pilot fuel consumption (APFC) that is required for the combustion process when using alternative fuels LPG, LNG, and Methanol fuel at different Engin loads in ton/year :

Table.9 Annul Pilot fuel consumption for each type of fuel in ton/year

	LPG APFC t/y	LNG APFC t/y	Met APFC t/y
100%	469.56	139.75	469.56
75%	436.02	129.96	436.02
50%	371.73	111.80	371.73
25%	296.27	89.44	296.27

The previous table provides us with the Annual Pilot Fuel Consumption for LPG, LNG, and Methanol. Pilot fuel is used to ignite the main fuel mixture in the combustion chamber, where a small amount of pilot fuel is injected at a location that is ignited by an electrical spark or a flame. This is done to ensure reliable and quick .ignition of the main fuel

From the previous table, we can infer that LNG has the lowest consumption among the three types, with a significant difference compared to LPG and Methanol. We also observe that Methanol and LPG have the same fuel consumption, which can be attributed to their reliance on the same principle of Liquid Gas Injection (LGI). On the other hand, LNG is injected based on the Gas Injection (GI) principle

When calculating **emissions**, we calculate both carbon dioxide (CO2) and nitrogen oxides (NOx) emissions for each type of fuel at different loads. As for particulate matter (PM) and sulfur oxides (SOx) emissions, we only calculated them for heavy fuel, as these emissions are negligible or can be disregarded in the case of LPG, LNG, and methanol. This is one of the main reasons that supports the shift towards using alternative fuels for ships.

The fourth IMO GHG Study has indicated that the emission factor for particulate matter (PM) is 7.55 kg per ton of fuel. Additionally, the emission factor for sulphr oxides (SOx) is 50.83 kg per ton of fuel The equation used for that is:

$$PM\ Annul\ emission = PM\ emission\ factor\ \ *\ Annual\ fuel\ consumption$$

$$Sox\ Annul\ emission = Sox\ emission\ factor\ \ *\ Annual\ fuel\ consumption$$

Table.10 HFO PM and SOx Annul emission in ton/year

Engine Load	Annul (SOx) emission	Annul PM emission
100%	475.76	70.66
75%	349.27	51.88
50%	234.98	34.90
25%	122.18	18.14

The following table represents the annual emissions of carbon dioxide (CO2) and nitrogen oxides (NOx) for each type of fuel at different loads in ton per year. And The equation used for that is:

$$CO2\ Annul\ emission = CO2\ emission\ factor\ \ *\ Annual\ fuel\ consumption$$

$$NOx\ Annul\ emission = NOx\ emission\ factor * Power * Annual\ Operating\ Hours$$

Table.11 CO2 and NOx Annul emission in ton/year

	HFO		LPG		LNG		Methanol	
	CO2	NOx	CO2	NOx	CO2	NOx	CO2	NOx
100%	29952	782.6	24819	503.1	21982	525.4	28676	111.8
75%	21989	586.9	17860	377.3	15795	394.1	20689	83.8
50%	14793	391.3	11823	251.5	10299	262.7	13667	55.9
25%	7691	195.6	6885	125.7	5303	131.3	6770	27.9

The previous table shows us the annual emission values and we can conclude from it that carbon dioxide and nitrogen oxide emissions were reduced when using LPG, LNG, and Methanol compared to HFO

Methanol achieved the highest reduction in nitrogen oxide emissions but also achieved the lowest reduction in carbon dioxide, despite it containing the least carbon among the other fuel types due to the higher amount of methanol used.

LPG and LNG achieved close Value in reducing nitrogen oxides, but LNG achieved a higher reduction in carbon dioxide compared to LPG. The reason is that LNG consists mainly of methane CH_4 and ethane C_2H_6, meaning it contains less carbon atoms than LPG which consists of propane C_3H_8 and butane C_4H_{10}

Since **fuel cost** represents the largest operational cost for the ship and is one of the main metrics in choosing ship fuels, we calculated the annual fuel cost for heavy fuel oil, liquefied petroleum gas LPG, liquefied natural gas LNG and methanol at different loads and the following table illustrates that

Table.12 Annul Fuel cost in US dollar

	HFO	LPG	LNG	Methanol
100%	5616000	5046652	3517228	10514790
75%	4122900	3631513	2527228	7586315
50%	2773740	2403949	1647932	5011435
25%	1442220	1399950	848540	2482645

The previous table clearly shows us that methanol is the most expensive type of fuel, while liquefied natural gas LNG is the least expensive in terms of cost. As for liquefied petroleum gas LPG, it is considered close to heavy fuel oil in terms of cost, due to its current high price

Although the annual fuel cost is one of the main factors in studying the economic feasibility of transitioning to alternative fuels, there are several other factors that must be taken into consideration when analyzing economic feasibility

Conclusion

In this study, we analyzed the use of alternative marine fuels LPG, LNG, methanol and compared them to heavy fuel oil in terms of annual fuel consumption, annual fuel cost, and emissions at different engine loads. We obtained the following results:

1-In terms of annual fuel consumption, methanol has the highest fuel consumption, while liquefied natural gas LNG has the lowest.

2-Reducing emissions is the main reason for shifting to alternative fuels. All LPG, LNG and methanol achieved complete elimination of particulate matter and sulfur oxide emissions. For carbon dioxide and nitrogen oxide emissions, we found reductions compared to heavy fuel oil. Methanol ranked first in terms of nitrogen oxide emission reductions. LPG and LNG achieved similar results in terms of nitrogen oxide emission reductions.

3-Reducing carbon dioxide emissions is one of the main goals of the International Maritime Organization in the future. When using alternative fuels, we observed reductions in carbon dioxide emissions. LNG is the best in terms of reducing carbon dioxide emissions, followed by LPG. Methanol results were close to heavy fuel oil.

4-LNG has the lowest annual fuel cost, while methanol has the highest cost. LPG has a slightly lower cost than heavy fuel oil.

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