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CALCULATION OF CO2 EMISSIONS FOR LNG AS A FUEL AND COMPARISON WITH THE HFO EQUIVALENT

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Abstract. *Introduction. Nowadays the environmental regulations are becoming stricter and stricter for international shipping industry. Modern ship owners and ship operators are trying to solve the issues concerning environmentally harmful emissions of working fleet. In addition, one of the ways to reduce environmentally harmful emission, according to International regulations, is the usage of less emissive kinds of fuel. However, more and more ship power plants are switching to dual-fuel or even triple-fuel configurations. In order to be ready in near future to commence the usage of the combination of different types of fuel and finally to switch fully to better solutions. These topics and subjects are becoming increasingly important every day, and the industry needs professionals who are ready to accept this challenge and make the industry less harmful to the environment.*

Purpose. This article presents research and analysis on the burning of old-fashioned and new types of fuel that are already changing the industry, as well as their combination and comparisons. The research data are collected during the performing of transatlantic voyage on LNG tanker equipped with Gas Chromatograph.

Methods and ways to control the energy efficiency of a ship power plant on the example of a loaded LNG tanker voyage. A practical example of the use of energy in an efficient way on the basis of data collected when the ship performed a typical voyage task.

Results. As the result, obtained difference ratio of the emitted quantity of CO2 for the usage of applicable amount of fuel to complete transatlantic voyage between the same ports and the same route.

Conclusions. In this article, analytical data are collected and analysed concerning energy characteristics of the gas composition. These data may vary from the original data that is provided as per the certificate of quality and as a result, it can be claimed that the usage of LNG as a main type of fuel is producing less CO2 emission during combustion.

Key words: *LNG, CO2, environmental regulations, dual fuel, emissions*

Introduction.

On modern LNG Tankers, it is becoming more and more popular to install gas chromatograph systems to track energy efficiency during laden and ballast voyages. Moreover, this part of the research is conducted by the shore side to track the information on both kind of voyages: laden and ballast.

A gas chromatograph (GC) is an analyzing instrument that measures the content of various components in a sample. The analysis performed by a gas chromatograph is called gas chromatography.

It constantly measures samples of the gas that passes through the flow meter. In this article, we are going to explore the energy released during combustion in ship power plants.

Ship power plants consist of a set of diesel generators that produce energy through the combustion of a mixture of gas and air inside the cylinders. The preset of running characteristics of diesel generators depends entirely on a typical voyage task to be completed.

As an example, North Atlantic Crossing voyage task will be described in the given article. All data are collected during the voyage since commencement of the ocean passage.

The energy content of any fuel, whether it is gas composition or fuel oil, is characterized by the amount of chemical energy stored within it, which is released as heat during combustion. This energy is measured in units like British Thermal Units (BTU) or megajoules (MJ).

While units of heat are often supplanted by energy units in scientific work, they are still used in some fields. For example, in the United States the price of natural gas is quoted in dollars per the amount of natural gas that would give 1 million BTUs (1 "MMBtu") of heat energy if burned.

In the given article MJ units are generally accepted and used, BTU is more used in commercial purposes. It is always easy to convert these units using simple formulas.

One BTU is approximately - 1.0551 kJ (kilojoules)

1.1 Main ship's characteristics

In the provided article, everything will be described using the example of a dual-fuel LNG tanker with four GTT Mark III type cargo tanks, a bulbous bow, and a transom stern. The vessel is equipped with a diesel-electric propulsion system.

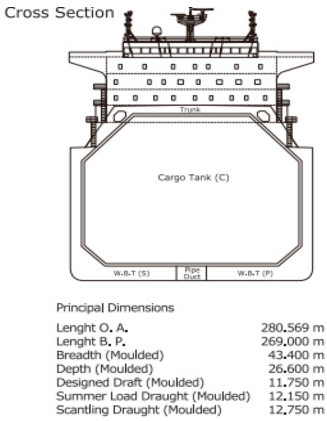


Fig. 1 – Cross-section of the reference LNG tanker, showcasing its GTT Mark III type cargo tanks.

1.2 Lower Heating Value and Higher Heating Value

There are two kind of Heating Values – LHV (Lower Heating Value) and HHV (Higher heating value). Meantime LHV is more important for obtaining calorific amount of energy released during combustion. LHV value is commonly used for calculation of energy efficiency during combustion in engines.

As long as the given LNG carrier is using cargo vapor as a fuel we can usually calculate initial calorific amount of energy in our gas mixture based on Certificate of Quality issued by the cargo provider. This value is important to us for future calculation of Fuel Oil Equivalent (FOE).

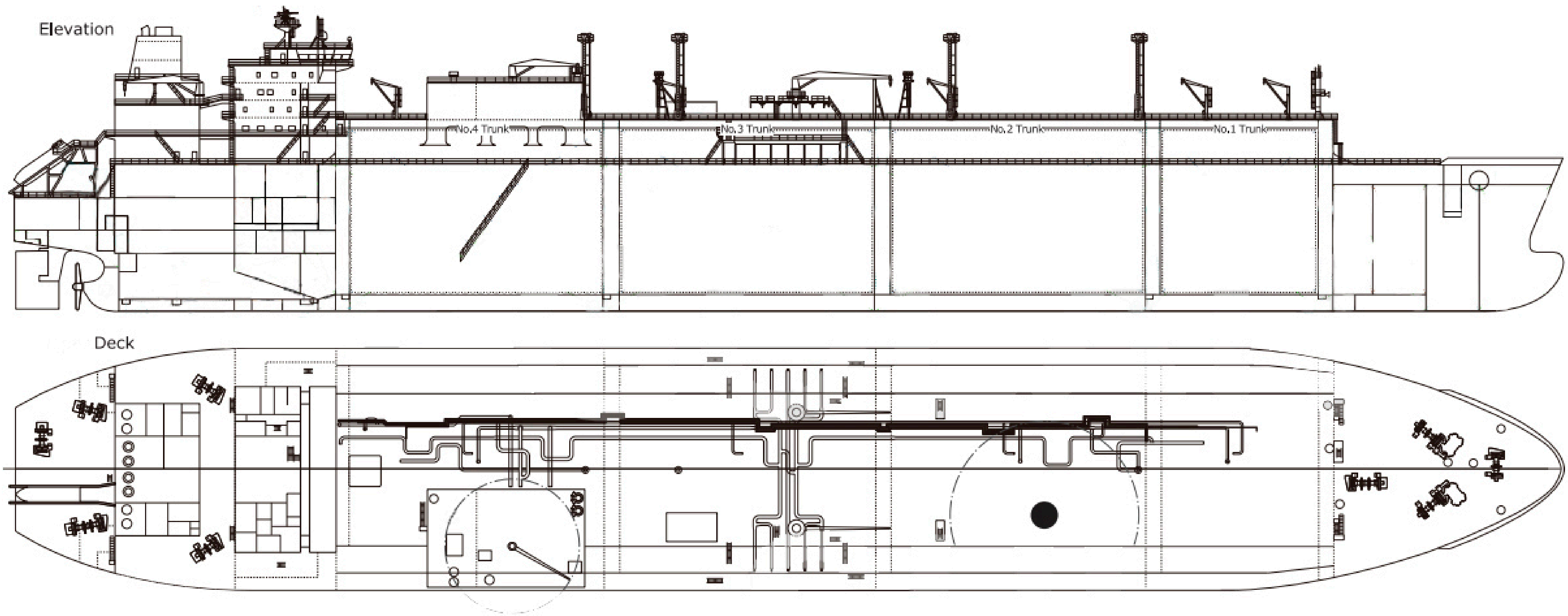


Fig. 2 - General arrangement of the reference LNG tanker, illustrating its bulbous bow and transom stern design.

2.1 Main Part. Calculation of specific energy for the LNG

Table 1 - Calculation of specific energy for the LNG

The specific energy (by mass) of the LNG can be calculated from the cargo composition. The molar fraction of each component is used in this calculation. Molar fraction data are available in the Cargo Quality report.

Component	Molar fraction	Molecular weight	Mass weigh	Mass fraction	Mass net calorific value*	Mass gross calorific value by fraction
	K1	K2	K3	K4	K5	K6
	%	g/mol	g	%	MJ/MT	MJ/MT
Methane (CH4)	97.01	16.0430	15.563	94.245	50029	47150
Ethane (C2H6)	2.69	30.0700	0.809	4.898	47510	2327
Propane (C3H8)	0.19	44.0970	0.084	0.507	46330	235
Isobutane (iC4H10	0.03	58.1230	0.017	0.106	45720	48
n-Butane (nC4H10)	0.03	58.1230	0.017	0.106	45720	48
Isopentane (iC15H12)	0.01	72.1500	0.007	0.044	45720	20
n-Pentane (nC5H12)	0.01	72.1500	0.007	0.044	45720	20
Nitrogen (N2)	0.03	28.0135	0.008	0.051	-	-
Total	100.000		16.514	100.000		**49849**
The specific energy of the LNG is		**49849**	**MJ/MT**			

Calculation steps are described below

K1	Molar fraction from cargo quality report
K2	Constant taken from cargo quality report
K3	Mass weight of each fraction: Molar fraction (Q1) x Molecular weight (Q2)
K4	Same as Q3, expressed as percentage of total mass weight: Q3/(sum of Q3)
K5	Constant taken from chromatograph
K6	Weighted contribution to the mass gross calorific value for each component. The total of this column is the specific energy of the actual LNG: Q5 x Q6

With the help of this table for the initial calculation of the specific energy for the LNG we are able to calculate fuel oil equivalent (FOE).

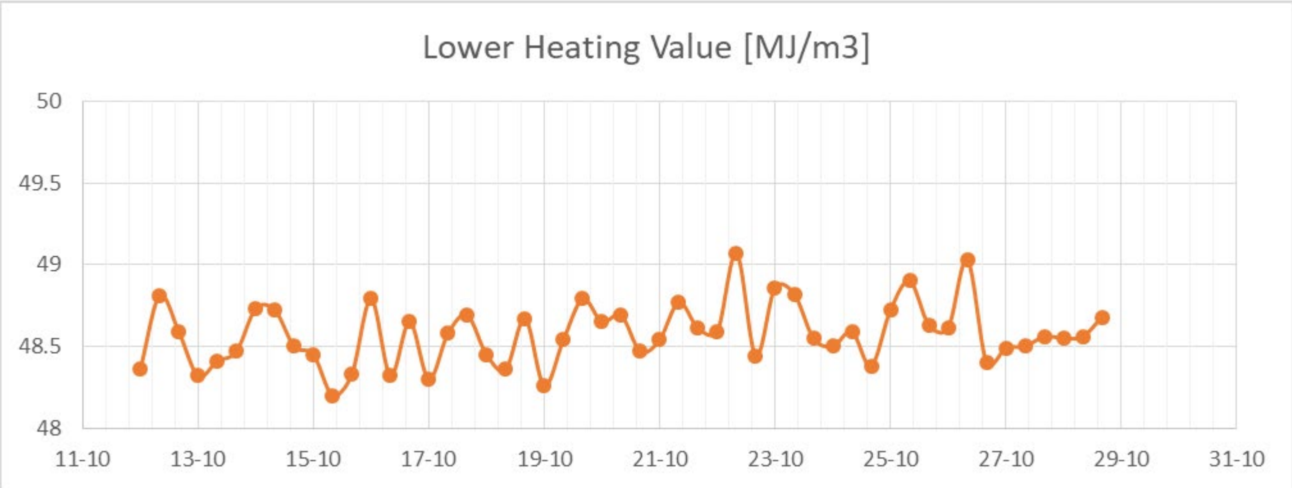
FOE – is a factor which describes the relation between the total energy in one CBM of LNG and one MT of diesel oil.

In addition to initial calculation of specific energy for the loaded LNG, ship is equipped with the real-time gas chromatograph and during the voyage it was collecting information every 8hr showing LHV content using certified and approved by Class and Flag chromatograph.

Table 2 – Fuel oil – LNG Conversion

FUEL OIL - LNG CONVERSION

The calculations below is used to find the fuel oil equivalent conversion (FOE) factor.				
Input data				
Description	**Unit**	**Value**	**Ref**	**Comment**
Specific energy LNG: From Cargo Quality Report *	MJ/MT	49849	K1	User input data
Specific energy HFO: From HFO Quality Report	MJ/MT	41300	K2	User input data
Cargo Density: From Cargo Quality Report	MT/CBM	0.429530	K3	User input data
Calculation of FOE conversion factor (based on input data)				
Total energy in one CBM LNG (conversion from MT to CBM) = K1 x K3	MJ/CBM	21411.64	K4	Intermediate calculation
FOE conversion factor: Energy LNG (MJ/CBM) / Energy HFO (MJ/MT) = K4 / K2	MT (HFO)/CBM (LNG)	**0.5184**	K5	
Simple fuel - LNG calculator (use calculated FOE conversion factor)				
quantity LNG ---------->	CBM	100	K6	This is equal to 51.8 MT HFO
quantity HFO ---------->	MT	52.74	K7	This is equal to 101.7 CBM LNG
Units and abbreviations				
1 CBM = 1 cubic metre = 1000 litres				
1 MT = 1 (metric) Tonne = 1000 kilograms				
1 MJ = 1 megajoule = 1000 kilojoule = 1 000 000 joule. 1 Joule = 1 watt times one second equals				
1 BTU/kg = 1.05505585 kJ/KG				



The graph of collected real-time LHV during passage is presented.

As it can be seen from graph, data are not so stable but we can take a median from collected data and it will equals to 48.560 MJ/m3.

The energy content of LNG, as measured by its Lower Heating Value (LHV), can vary due to the amount of methane vapor produced in the tank under different weather conditions. However, even with these fluctuations, the LHV of LNG is generally higher than that of LSHFO (Low Sulfur Heavy Fuel Oil). This higher energy content is a significant advantage of LNG over traditional marine fuels.

Therefore, as we have all necessary data, we can proceed with the comparison of CO_2 emission for both kinds of fuel during combustion.

2.2 CO_2 emissions

Combustion in the diesel generators is happening in the same way for both kinds of fuel, namely: gas vapour or LSHFO, for both of them we will consume LSMGO on daily basis as pilot fuel, depending on the amount of generators which is used, it may vary from 0.6 MT to 1.5 MT per 24hrs. So due to that fact we can exclude for comparison of CO2 emissions during combustion of LNG.

The following emission factors of CO2 for combustion of each fuel MT can be announced with reference to IMO – MEPC 80/17/Add 1. Annex 14.

Combustion of 1t of VLSFO emits about 3.15t of CO2;

$$CO_{2\,VLSFO} = 3.15t$$

Combustion of 1mt of LNG emits about 2.75t of CO_2;

$$CO_{2\,LNG} = 2.75t$$

During the voyage from 12/10 to 28/10 3168.9 m3 of LNG was consumed in the combination set for diesel generators.

LNG Quantity = **3168.9 m3**

FOE = **0.5184**

LNG density = **429.530 kg/m3 = 0.429530 MT/m3**

Converting needed VLSFO using FOE factor by formula (1):

$$VLSFO = LNG * FOE \tag{1}$$

$$VLSFO = 3168.9 * 0.5184 = 1642.6\ MT$$

The following formula (2) can be used to calculate emitted CO_2 quantity:

$$CO_2 = CO_2 emission\ factor\ * q'ty\ fuel \tag{2}$$

For proper calculation, we have to convert m^3 of consumed LNG to MT to apply emission factor during combustion. It will be done with the help of the formula (3):

$$LNG[MT] = LNG[m3] * density[MT] \tag{3}$$

$$LNG[MT] = 3168.9 * 0.429530 = 1361.1\ MT$$

For LNG emitted CO_2 will be calculate with the help of this formula (4):

$$CO_{2LNG} = 2.75 * 1361.1 = 3743.1\ t \tag{4}$$

For VLSFO emitted CO_2 will be calculate by this formula (5):

$$CO_{2VLSFO} = 3.15 * 1642.6 = 5174.2\ t \tag{5}$$

Let's distinguish the difference in % ratio of reduction CO_2 emissions by formula (6):

$$\frac{(CO_{2VLSFO} - CO_{2LNG})}{CO_{2VLSFO}} * 100 \tag{6}$$

We will get this ratio:

$$\frac{(5174.2 - 3743.1)}{5174.2} * 100 = 27.66\ \%$$

In this ratio calculation excluded emission of CO_2 caused by pilot fuel. But if we take on daily basis consumption of 1.2MT of LSMGO as pilot fuel for 16 days it contains additional 19.2mt of fuel. Emission factor - 3.2 t of CO_2 for consumption of 1 MT of MDO. This usage will add additional 61.44 t of emitted CO_2 to both kinds of

Summary and conclusions.

The modern shipping industry is constantly seeking innovative and efficient solutions to improve emissions control and energy efficiency. One promising avenue is the development of hybrid power plants that can operate on multiple fuel types, often combined with battery storage systems.

This article presents valuable research for the shipping industry, demonstrating how these modern solutions contribute to a more environmentally friendly maritime sector. Specifically, we delve into the energy characteristics of gas compositions used as fuel in hybrid power plants. Notably, we highlight that the actual gas composition can vary from the values stated in the certificate of origin, as shown in the calculation method for net calorific value (NCV) in Table 1.This variability can affect the energy efficiency of the power plant and, consequently, the ship's overall emissions. Depending on the quantity of methane, we can conclude that composition can consist of bigger calorific energy. We assume that fuel oil equivalent may differ depending on the composition of the liquefied natural gas (LNG) and very low sulfur (VLSFO) oil that is available onboard.

Moreover, the data obtained during the voyage supports the widely accepted notion that switching to liquefied natural gas (LNG) as a fuel source can contribute to a reduction in CO_2 emissions.

In conclusion, our analysis, based on a real-world example of a seagoing vessel completing typical voyages, demonstrates that utilizing liquefied natural gas (LNG) as an alternative fuel source can potentially reduce CO_2 emissions by 27% per ship. While this initial assessment suggests a promising reduction in CO_2 emissions, it is important to acknowledge that this study does not account for potential methane slip, a greenhouse gas with a significantly higher global warming potential than CO_2. Furthermore, the analysis does not consider the additional CO_2 emissions associated with the more complex infrastructure and power plant design required for LNG bunkering and utilization.

While the focus of this article is on CO_2 emissions, it is crucial to recognize that other harmful emissions, such as soot, carbon monoxide (CO), and nitrogen oxides (NOx), also contribute to environmental concerns and are not addressed in this study.

Despite these limitations, the findings highlight the potential of LNG as a transitional fuel in the maritime industry's ongoing efforts to reduce its environmental impact and move towards a more sustainable future. Further research is needed to comprehensively assess the overall environmental impact of LNG, including methane slip and the full lifecycle emissions associated with its production, transportation, and use.

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