Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 59 (2014) 243 – 248

Energy Procedia

European Geosciences Union General Assembly 2014, EGU 2014

The influence of different types of marine fuel over the energy efficiency operational index

Nicoleta Acomi[a]*, Ovidiu Cristian Acomi[b]

[a]*Constanta Maritime University, 104 Mircea cel Batran St., Constanta 900663, Romania*
[b]*Project Masters Nig. Ltd., Km14 Aba Expressway, Port Harcourt PO Box 3861, Nigeria*

Abstract

One of the main concerns of our society is certainly environmental protection. The international efforts for maintaining a clean environment are various and this paper refers to the efforts in the maritime transport field. The subject of our study is the concept of Energy Efficiency Operational Index (EEOI), developed to provide ship-owners with assistance in the process of establishing the emissions from ships in operation, and to suggest the methods for achieving their reduction. As a monitoring tool, EEOI represents the mass of CO_2 emitted per unit of transport work. Using the software developed by the authors, it will emphasize the variation of the EEOI value for one vessel using different types of fuel during the laden and ballast voyages, for a period of three months, as stated in the Ship's Log Books. The main consumers considered are Main Engine, Diesel Generators and steam Boilers, and the types of fuel used will be as per charter party agreements and following the specific international and local rules and regulations. The results for the quality parameter EEOI and the average cost of achieving them will be included in compared cost-to-quality graphs, in order to underline the profitability of the studied methods for minimizing the air emissions.

Peer-review under responsibility of the Austrian Academy of Sciences

Keywords: Energy Efficiency Operational Index; carbon dioxide emissions; air pollution; maritime transport;

1. Introduction

Marine pollution refers to water pollution and air pollution. Regardless of the delay in recognizing the later type of pollution, it rapidly gained many organizations to argue on it. The first step was including a dedicated annex

* Corresponding author. Nicoleta Acomi. Tel.: +40-241-664-670.
E-mail address: nicoleta.acomi@cmu-edu.eu

Peer-review under responsibility of the Austrian Academy of Sciences
doi:10.1016/j.egypro.2014.10.373

(Annex VI) in the International Convention for the Prevention of Pollution from Ships, in 1997 [1], which seeks to minimize the airborne emissions from ships. International shipping is the most environmental-friendly and energy efficient mode of mass transport and only a modest contributor to the total volume of atmospheric emissions while moving a considerable part of world trade (90%) [2]. In order to control and minimize air pollution, the International Maritime Organization has identified CO_2, SOx and NOx as major pollutants and has also developed a series of measures for monitoring emissions [3]. As for CO_2, these measures are grouped in three main directions. These are technical, operational and management related:

- Energy Efficiency Design Index;
- Energy Efficiency Operational Index;
- Ship Energy Efficiency Management Plan.

Nomenclature

EEOI	Energy Efficiency Operational Index
CO2	Carbon Dioxide
IMO	International Maritime Organization
j	the fuel type
i	the voyage number
FC ij	the mass of consumed fuel *j* at voyage *i*
CFj	the fuel mass to CO_2 mass conversion factor for fuel *j*
m_{cargo}	cargo carried (tonnes) or work done (number of TEU or passengers) or gross tonnes for passenger ships
D	distance (in nautical miles) corresponding to the cargo carried or work done
TEU	Twenty foot Equivalent Unit

1.1. Concept of EEOI

The concept of EEOI is an instrument developed by the IMO in order to provide ship-owners, ship operators and other parties involved with a mechanism to determine the level of greenhouse gas emissions from ships in operation. The IMO's considerations on EEOI were included in the Guidelines for voluntary use of the ship energy efficiency operational indicator MEPC.1/Circ.684 (2009) [4], which recommend the EEOI as a helpful tool for the limitation of the impact of shipping on global climate change. These Guidelines are intended to provide an example of a calculation method which could be used as an objective, performance-based approach to monitor the efficiency of a ship's operation. The Guidelines present the concept of an indicator for the energy efficiency of a ship in operation, expressed in the form of CO_2 emitted per unit of transport work, in which a smaller EEOI value means a more energy efficient ship:

$$EEOI = MCO_2 / Transport\ Work \quad (1)$$

where the CO_2 emitted is measured based on the fuel consumption and the transport work is the cargo mass (T) multiplied by the total distance sailed in nautical miles (Nm). The terms of the equation are as follows:

- Distance Sailed – the actual distance sailed in nautical miles for the respective voyage, as recorded in the ship's Bridge Log Book;
- Cargo mass – in this case expressed in tonnes, quantity as per Bill of Lading and Deck Log Book; for other types of vessels the work done will be expressed in a different manner: for passenger ships – number of passengers, for car ferries – number of cars;

- Fuel consumption represents all the fuel consumed at sea and in port by main and auxiliary engines, boilers and others, as recorded in Engine Log Book.

The EEOI for a voyage is calculated by the following formula, in which a smaller EEOI value means a more energy efficient ship:

$$EEOI = \frac{\sum_j FC_j \times C_{Fj}}{m_{cargo} \times D} \quad (2)$$

For a number of voyages or voyage legs, the indicator is expressed as:

$$AverageEEOI = \frac{\sum_i \sum_j \left(FC_{ij} \times C_{Fj}\right)}{\sum_i m_{cargo,i} x D_i} \quad (3)$$

1.2. Types of marine fuel

The relationship between fuel consumption and mass of CO_2 comes from the chemical composition of the fuel, which mainly consists of hydrocarbons, e.g. $C_{15}H_{32}$. Carbon (C) has an atomic weight of 12.011, while Hydrogen (H) has an atomic weight of 1. This yields carbon with a mass fraction limited to the range of 85% to 87.5%, where diesel oil is in the higher % range and heavy fuel in the lower % range [5] (see Table 1). When combusted hydrocarbons react with oxygen (O_2), which has an atomic weight of 15.9994 then for each CO_2 one C is needed. Using the atomic weights, the ratio between CO_2 and carbon is 3.664. Multiplying the mass fraction of carbon in the fuel we get the specific emission of CO_2 (CF). For different types of fuel, we have different carbon content and, consequently, different correction factor [4]:

Table 1. The Carbon content per fuel type.

Type of fuel	Reference	Carbon Content	CF (t-CO_2/t-Fuel)
Diesel / Gas Oil	ISO 8217 Grades DMX through DMC	0.875	3.206000
Light Fuel Oil (LFO)	ISO 8217 Grades RMA through RMD	0.86	3.151040
Heavy Fuel Oil (HFO)	ISO 8217 Grades RME through RMK	0.85	3.114400
Liquefied Petroleum Gas (LPG)	Propane;	0.819	3.000000
	Butane	0.827	3.030000
Liquefied Natural Gas (LNG)		0.75	2.750000

The next chapter will emphasize the change of EEOI by varying different types of marine fuel. The maritime industry uses mainly the following kinds of fuel: Marine Diesel Oil/Gasoil, Light Fuel Oil and Heavy Fuel Oil.

2. Case study

This study is based on the characteristics of an Aframax Oil Tanker of 107157 DWT, equipped with a MAN B&W 6S60MC-C Main Engine (ME) of 13560KW at 105RPM, three Daihatsu 6DK20 Diesel Generator (DG) Sets of 960KW and 900RPM and two Aalborg Mission TM OL Auxiliary Boilers (AB) of 18bar working pressure and

25t/h steam capacity. Basis of the analysis were considered the completed voyages of the oil tanker, performed during the third quarter of 2013. The term “voyage” is defined as the period between the departure from a port to the departure from the next port of call (both Ballast and Laden). The analysis includes only voyages which have been completed within the quarter. As per the IMO guidance [4], the voyage commenced before the beginning of the quarter (departure from a port) and ended within the quarter (departure from the next port), has been reported for this quarter.

The method used for studying the situations stated above is the comparative analysis, varying the type of fuel used during the same voyages performed during the quarter, while the other voyage parameters are maintained constant. The first situation being analyzed takes into account a voyage completed by our vessel, an Aframax Oil Tanker, engaged on spot market, which completed the following voyages (see Fig. 1):

- 59L Arzew (Algeria) to Tetney (UK), started on 10th of June 2013 and completed on 3rd of July 2013
- 60B Tetney (UK) to Kerch (Ukraine), started on 3rd of July 2013 and completed on 25th of July 2013
- 60L Kerch (Ukraine) to Sabine (USA), started on 25th of July 2013 and completed on 31st of August 2013
- 61B Sabine (USA) to Cayo Arcas (Mexico), started on 31st of August 2013 and completed on 9th of September 2013

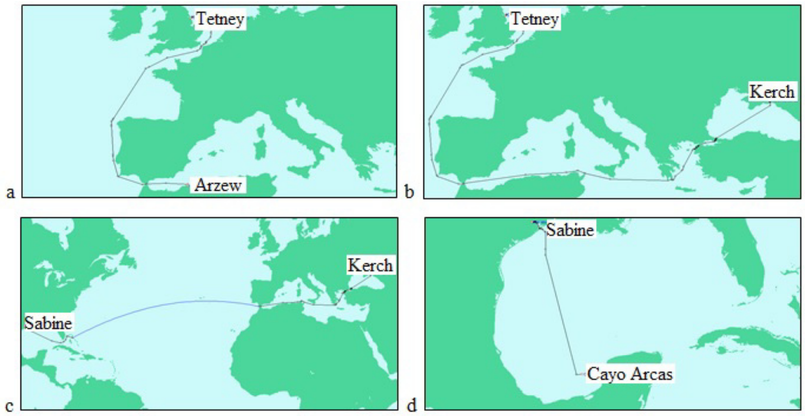

Fig. 1. (a) Arzew to Tetney; (b) Tetney to Kerch; (c) Kerch to Sabine; (d) Sabine to Cayo Arcas.

The type of fuel used during the voyage was Heavy Fuel Oil (HFO) ISO 8217 grades RME through RMK, as stated in the Charter Party Agreement, subject to international and local regulations. Such local regulation applies for the port of Tetney (UK), i.e. the EU Directive 2005/33/EC regarding the usage of low sulphur fuel in European Union ports and harbour areas [6]. Consequently, out of the total quantity of 320.3MT, a quantity of 36.1MT of Marine Gas Oil ISO 8217 grades DMX through DMC has been used during voyage 59L. During the quarter, 178,044MT total amount of cargo has been shipped over a total distance of 12,279Nm (see Fig. 2).

Having calculated the fuel consumption during the quarter and having converted it into CO_2 mass by carbon content of the fuel, the EEOI emerges a function of the latter, the cargo mass and the distance sailed. A value of 7.79 is obtained for the EEOI in this case, value used in the paper as a reference point. As the amount of CO_2 emitted from ships is directly related to the fuel consumption, the EEOI can also provide useful information on a ship’s performance with regard to fuel efficiency and be used by the ship-owners and ship-operators as a tool to monitor the fuel consumptions and, ultimately, to help to find cost reductions.

HFO REAL

VOYAGE	Voyage Period		Fuel Consumption [mt]			Voyage Data		Work Generated [mt x Nm]
	From	To	Diesel / Gasoil	Light Fuel Oil	Heavy Fuel Oil	Cargo [mt]	Distance [Nm]	m_{cargo} x D
59L Arzew-Tetney	6/10/2013	7/3/2013	36.1	0.0	284.2	79,812	1,578	125,943,336
60B Tetney-Kerch	7/3/2013	7/25/2013	0.0	0.0	451.0	0	3,713	0
60L Kerch-Sabine	7/25/2013	8/31/2013	0.0	0.0	1067.2	98,232	6,431	631,729,992
61B Sabine-Cayo Arcas	8/31/2013	9/6/2013	0.0	0.0	54.5	0	557	0
TOTAL	6/10/2013	9/6/2013	36	0	1,857	178,044	12,279	757,673,328
C_F (gCO2/t Fuel) as per IMO MEPC.1/Circ.684			3,206,000	3,151,040	3,114,400			S = Σ(m_{cargo} x D)
CO2 Emissions		C = Σ(FC x C_F)		5,899	mt CO2			
EEOI		EEOI = C / S		7.79	gCO2/mt x Nm			

Fig. 2. EEOI value while using Heavy Fuel Oil.

The vessel has been consuming mainly HFO, due to its lower price. In case of using other types of fuel available on the market, having different carbon content, the value of the CO_2 conversion factor CF changes and finally the EEOI changes, as demonstrated below, for the situations using Marine Gas Oil (MGO) or Marine Diesel Oil (MDO) ISO 8217 grades DMX through DMC and for Light Fuel Oil (LFO) ISO 8217 grades RMA through RMD (Fig. 3).

In the first case, the use of Marine Gas Oil (MGO) or Marine Diesel Oil (MDO) determines an increase of the total CO_2 emissions during the quarter to 6069MT and consequently an increase of the EEOI to 8.01, as shown in Fig. 3:

MDO/MGO

VOYAGE	Voyage Period		Fuel Consumption [mt]			Voyage Data		Work Generated [mt x Nm]
	From	To	Diesel / Gasoil	Light Fuel Oil	Heavy Fuel Oil	Cargo [mt]	Distance [Nm]	m_{cargo} x D
59L Arzew-Tetney	6/10/2013	7/3/2013	320.3	0.0	0.0	79,812	1,578	125,943,336
60B Tetney-Kerch	7/3/2013	7/25/2013	451.0	0.0	0.0	0	3,713	0
60L Kerch-Sabine	7/25/2013	8/31/2013	1067.2	0.0	0.0	98,232	6,431	631,729,992
61B Sabine-Cayo Arcas	8/31/2013	9/6/2013	54.5	0.0	0.0	0	557	0
TOTAL	6/10/2013	9/6/2013	1,893	0	0	178,044	12,279	757,673,328
C_F (gCO2/t Fuel) as per IMO MEPC.1/Circ.684			3,206,000	3,151,040	3,114,400			S = Σ(m_{cargo} x D)
CO2 Emissions		C = Σ(FC x C_F)		6,069	mt CO2			
EEOI		EEOI = C / S		8.01	gCO2/mt x Nm			

Fig. 3. EEOI value while using Marine Diesel Oil/Marine Gas Oil.

In the second case, using Light Fuel Oil (LFO – see Fig. 4) shows an increase of the total CO_2 emissions during the quarter to 5967MT, raising the EEOI to 7.88 for the same voyages during the same quarter:

LFO

VOYAGE	Voyage Period		Fuel Consumption [mt]			Voyage Data		Work Generated [mt x Nm]
	From	To	Diesel / Gasoil	Light Fuel Oil	Heavy Fuel Oil	Cargo [mt]	Distance [Nm]	m_{cargo} x D
59L Arzew-Tetney	6/10/2013	7/3/2013	36.1	284.2	0.0	79,812	1,578	125,943,336
60B Tetney-Kerch	7/3/2013	7/25/2013	0.0	451.0	0.0	0	3,713	0
60L Kerch-Sabine	7/25/2013	8/31/2013	0.0	1067.2	0.0	98,232	6,431	631,729,992
61B Sabine-Cayo Arcas	8/31/2013	9/6/2013	0.0	54.5	0.0	0	557	0
TOTAL	6/10/2013	9/6/2013	36	1,857	0	178,044	12,279	757,673,328
C_F (gCO2/t Fuel) as per IMO MEPC.1/Circ.684			3,206,000	3,151,040	3,114,400			S = Σ(m_{cargo} x D)
CO2 Emissions		C = Σ(FC x C_F)		5,967	mt CO2			
EEOI		EEOI = C / S		7.88	gCO2/mt x Nm			

Fig. 4. EEOI value while using Light Fuel Oil

3. Comparative analysis

Considering fuel consumption (as stated in the Engine Log Book) and voyage data (cargo and distance) the variation of the EEOI value for using different types of fuel during the laden and ballast voyages is shown in Fig. 5. In order to underline the profitability of the studied methods for minimizing the CO_2 emissions, the results for the quality parameter EEOI and the average cost of achieving them were included in compared cost-to-quality graphs. The average prices per metric tonne of marine fuel were extracted from the international oil market: 580 USD/MT of HFO, 885 USD/MT of MDO/MGO and 655 USD/MT of LFO [7].

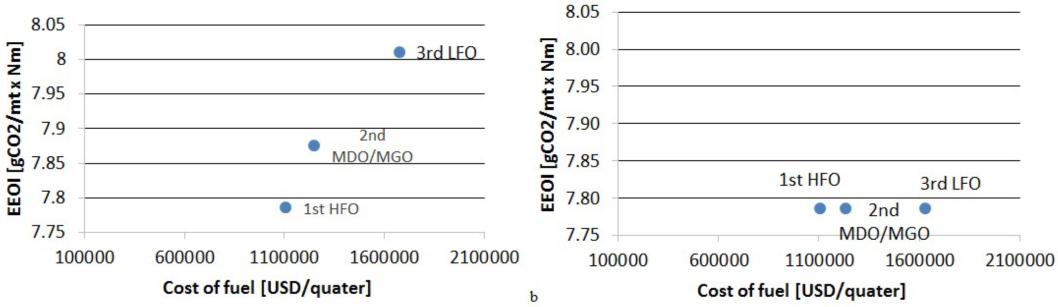

Fig. 5. (a) Total cost for using different types of marine fuel for the same quarter, (b) Fuel consumption variation for keeping the same level for EEOI value.

4. Conclusions

Improvements in energy efficiency are possible by operational measures, such as using different types of fuel for the different consumers, depending on voyage legs. Slight differences of less than 3% can be noticed in EEOI value, while changing the type of fuel, with a total cost variation of up to 20-50%. As observed from the results above, to the most cost effective type of fuel (HFO) corresponds to the smallest value of EEOI (to the less pollutant situation). Comparing with the use of HFO, using the MDO/MGO, determines a 2.82% higher value of the EEOI, while using the LFO leads to an increase of the EEOI of 1.15%.

References

[1] IMO. International Convention for the Prevention of Pollution from Ships. Adoption 1973, Protocol 1978, Protocol Annex VI 1997.
[2] IMO. MEPC 59/INF.10, Second IMO GHG Study; 2009.
[3] IMO - Agenda item 9/a. Emissions from fuel used for international aviation and maritime transport, Technical and operational measures to improve the energy efficiency of international shipping and assessment of their effect on future emissions; 2011.
[4] IMO. MEPC.1/Circ.684, Guidelines for voluntary use of the ship energy efficiency operational indicator, EEOI; 2009.
[5] IMO. MEPC.1/Circ.471.CO_2, Interim guidelines for voluntary ship CO_2 emission indexing for use in trials; July 2005.
[6] EU Directive 2005/33/EC regarding the usage of low sulphur fuel in European Union ports and harbour areas; 2005.
[7] www.bunkerworld.com/prices; accessed April 2014.