



Modelling Energy Efficiency for Voyage of Chemical Tanker Vessel (CTV) Operating in Calm Weather Condition

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Abstract: An increased study into improving ship energy management has been prompted by worldwide worries about the high cost of bunker fuel. The study present both empirical and analytical approaches considered in predicting the vessel fuel consumption and the hull resistance of a chemical tanker vessel on a voyage from Escavos, Delta to Lagos port (Apapa) in Nigeria enroute Lome port (Togo) and Tiko port (Cameroon). The speed and route of a ship must be determined by balancing numerous objectives such as cost, arrival time, and cargo safety. DMarine Book, a computer model that employs the Holtrop technique to calculate vessel power and resistance power was designed to estimate the degree of energy efficiency by the deployment of energy efficient technologies. The semi empirical model was used in the development of C shape code for simulating energy efficiency. The approach was used to develop the model for predicting the vessel resistance, EEOI for a given fuel consumption hence reducing the overall emission level of the vessel as part of the implementation of ship energy efficiency management plan (SEEMP). The built software (DMarine Book) can be used as a decision tool for operators of the chemical Tanker vessel onboard. Under calm weather conditions, operating the chemical tanker vessel at a speed of 12.18 knots (economical speed) rather than a speed of 14.5 knots (rated speed) resulted in a reduction in vessel resistance of about 159.17kn and decrease in fuel consumption. The results are considered consistent with those of other authors who employed various models and similar operating conditions and came to similar conclusions. When running a vessel at an economically efficient speed, the Energy Efficiency Operational Indicator (EEOI) calculation shows a decrease in EEOI and Carbon Dioxide (CO₂) emission.

Keywords: Energy Efficiency at Voyage, Fuel Consumption, Emission, D Marine Book

1. Introduction

As the population of the world's grows, there has been a high demand for energy, meeting the rising need for energy in a safe, ecologically friendly manner is a major issue, since demand increase on a daily basis, necessitating the operation of the ship in the least energy efficient method feasible. Since shipping is one of the most important forces driving the globalized economy, accounting for over 80% of global trade in terms of volume and 70% in terms of value [1], It is sometimes described as a single source of the greenhouse gas emissions (GHG) that cause

climate change. Energy-efficient measures need to be implemented with intentional effort in order for GHG to be reduced to an acceptable level during the next ten years. In 2007, it was estimated that shipping produced 1046 million tons of CO₂. (Roughly 3.3% of global CO₂. The International Maritime Organization (IMO) predicts that CO₂ emissions will triple by 2050, with international shipping expected to be responsible for 2.7 percent of world CO₂ emissions in 2007 [2]. In response to the International Maritime Organization (IMO) forecast, the IMO has proposed a regulation on maritime energy efficiency which was released in January 2013 with the aim of reducing the

impact of shipping to global CO₂ emission [3, 4] through a reduction in fuel usage. The method employed to achieve this aim was to improve shipboard operation, upgrading shipboard equipment, optimization of ship design, employing good energy efficiency techniques and deploying new technologies in to shipping. According to the rule, all new and existing ships that weigh more than 400 gross tons must have an approved ship energy efficiency management plan (SEEMP) in place [5]. Following an increase in want for economic shipping, greater effort is channeled towards advance energy efficient measure in the shipping operation. Commercial shipping uses heavy fuel oil or intermediate fuel oil (HFO or IFO) which is known as a cheap type of bunker fuel. Bunker fuel cost is rising along with those of other petroleum products, and it cost could account for 50-60% of the total ship operational cost [6]. The present work focuses on the modelling energy efficiency for voyage of chemical tanker vessel by paying a close look on EEOI and CO₂ emission level. The route selection was done using the Meteorological and Oceanographic data during its voyage. The effectiveness of the maritime weather forecast and regular updates to the forecast are the primary factors that affect the voyage optimization procedure. The energy saved during the ship voyage, the route considered is from Escavos, Delta State to Lagos port (Apapa) in Nigeria enroute Lome port (Togo) and Tiko port (Cameroon) [7] and the obtained result was used for developing the resistance model for different ship speed.

2. Materials and Methods

Microsoft Excel combined with (CSharp) for programming is used to analyze the studies. To forecast how the ship will perform on its journey, the DMarine Book computer software was created. Table 1 below contains the particulars of the case study vessel (chemical tanker).

Table 1. Chemical/oil tanker particulars.

(ST NENNE)		
Parameters	Units	Value
Length Overall of the vessel	M	183
Length Between Perpendicular (LBP)	M	173.9
Moulded breadth	M	32.2
Depth Main Deck	M	18.8
Maximum Load Line Draft	M	12.25
midship		
Deadweight	Ton	46168
Gross Tonnage	Mt	30018
Net tonnage	Mt	11781
Wight displacement	10196	
Rated speed	Knot	14.5
Propeller	3-blade propeller	
The Engine type	Diesel	
The Engine builder	Man B&W	
RPM of the Engine	127	
The Stroke type	2	
The Cylinder bore	500	
The Cylinder stroke	2000	
Engine total power	Kw	8683
Engine total power	HP	11805
Propulsion type	fixed pitch	

2.1. Mathematical Model

The well-known Holtrop and Mennen's method is used to determine the ship's resistance [8]. This method allows for the prediction of the overall resistance over a wide range of ship sizes, hull types, and Froude values. In these investigations, the method is utilized to calculate the ship's overall resistance in calm water.

The ship total resistance can be expressed as:

$$R_{TOTAL} = R_F * (1 + K_1) + R_{APP} + R_W + R_B + R_{TR} + R_A \quad (1)$$

Where:

R_{TOTAL} = Ship total resistance in calm water (KN)

R_F = Ship frictional resistance (KN)

$(1+K_1)$ = Form factor

R_W = Wave breaking resistance and wave making (KN)

R_B = Additional pressure resistance of bulbous bow near the water surface (KN)

R_{TR} = Additional pressure resistance of immersed transom stern

R_{APP} = Appendages resistance (KN)

R_A = Ship correction resistance (KN)

The model equation for estimating the added resistance was first presented by kwon's approach [9].

$$V_{loss} = a_{correction} * \mu_{reduction} * \frac{\Delta V}{V} 100\% \quad (2)$$

Given:

ΔV = The speed loss due to head weather

V = design service speed

$\frac{\Delta V}{V}$ = The speed loss in head weather

$a_{correction}$ = Speed correction factor:

For block coefficient C_B and

Froude number F_n .

$\mu_{reduction}$ = The weather reduction factor

$$\frac{\Delta V}{V_1} 100\% = C_\beta * C_\mu * C_{form} \quad (3)$$

Given:

C_β = Direction reduction coefficient, dependent on the weather direction angle (with respect To the ship's bow) and the Beaufort number BN (Bft).

C_μ = Speed reduction coefficient, dependent on the ship's block coefficient C_B , the loading condition and the Froude number F_n

C_{form} = Ship form coefficient.

Where

$C_\beta = \mu_{reduction}$

$C_\mu = a_{correction}$

C_{form} = Ship form coefficient.

The 14-days operational time was used to predict the EEOI, CO₂ emission level, and energy savings.

Table 2 Shows data.

Table 2. Fuel consumption of a Chemical Tanker Vessel.

Weeks	Fuel Type	Mt/hour	Mt/day	Mt/week
week one	IFO at sea	1.583	38	266
Week Two	IFO at sea	1.625	39	273
Average		1.604	38.5	269.5
Week one	MDO at sea	0.095	2.3	16.1
Week Two	MDO at sea	0.10	2.5	17.5
Average		0.0975	2.4	16.8
Week one	MDO at Port	0.1125	2.7	18.9
Week Two	MDO at Port	0.104	2.5	17.5
Average		0.1082	2.6	18.2

2.2. Energy Efficiency Operational Indicators (EEOI)

The International Maritime Organization (IMO) developed the EEOI, which is identical to the EEDI, as a tool for assessing CO₂ gas emission levels to the environment because of transport operations in shipping. It shows the ships actual transport efficiency during its operation.. A ship that is more energy efficient has a lower EEOI value [2, 10]. EEOI is expressed as

$$EEOI = \frac{\sum FC_j * CF_j}{m_{cargo} * D} \quad (4)$$

The indicator is calculated as follows given data over several voyages:

$$Average EEOI = \frac{\sum_i \sum_j (FC_{ij} * CF_j)}{\sum_i (m_{cargo} * D_i)} \quad (5)$$

Given:

j = fuel type

I = voyage number

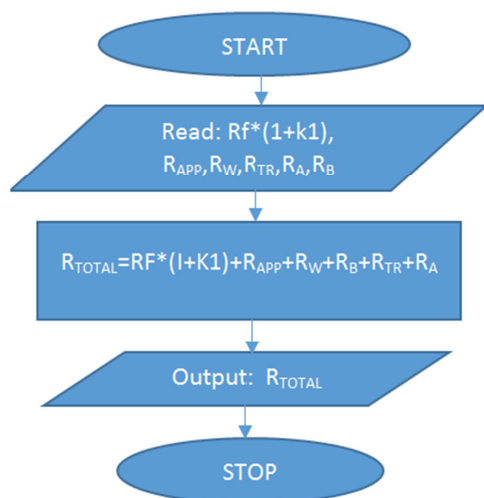
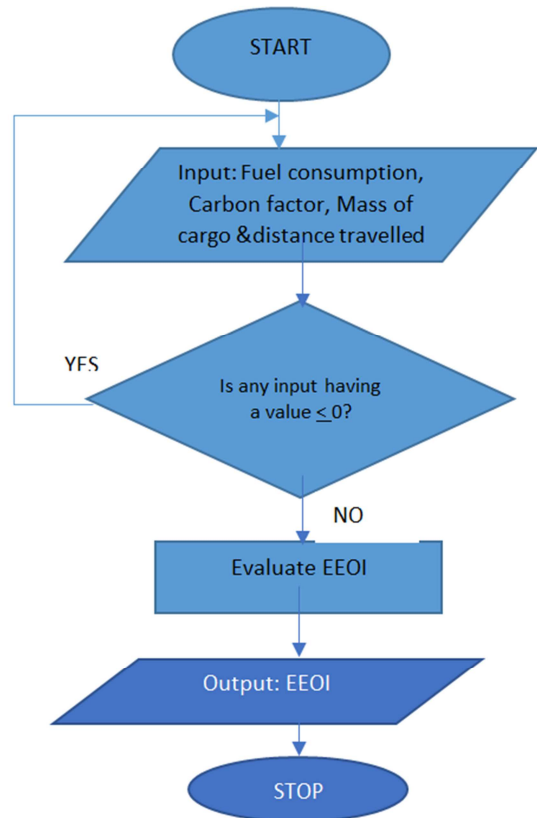
FC_{ij} = mass of consumed fuel of j during voyage i

CF_j = The CO₂ mass to fuel mass conversion factor for fuel j.

M_{cargo} = cargo carried in (ton) or the work done

D = Distance in nautical miles corresponding to the cargo work done.

Flow charts used for modeling the vessel Total resistance, EEOI and Fuel consumption during voyage are shown in figures 1, 2 and 3.

**Figure 1.** Flow chart for Total ship resistance R_T .**Figure 2.** Flow chart for Energy Efficiency Operational Indicator (EEOI).

3. Results and Discussion

The result presented is obtained from the developed software DMarine Book. In order to obtain specific/reduction in fuel consumption and emission level and hence improving the overall energy efficiency of the vessel certain performance of the vessel was properly analysed based on previous researches [11, 12]. In recent years, there have been studies on energy efficiency of vessels particularly offshore support vessels and passenger vessels. However, most of the researches used Mat Lab simulation models and some used mathematical approaches in analyzing the energy efficiency of their case study vessels at a given sea state [13, 14]. In addition, the effect of hull shape, ship block coefficient, draft trim and ship route on EEOI of a vessel has been researched on. The energy efficiency improvement with particular interest in the engine has been extensively investigated. It has been seen that for most researchers the key interest is on how to make the vessel more energy efficient through improvement on the engine system. It is on this note that this research looks at what area of the vessel can be improved that will give a positive energy improvement. It is hence important to investigate vessel resistance on the fuel consumption, EEOI and the emission level of the vessel at certain load during its voyage [15]. The gap is filled by this research. Based on proper investigation of the individual resistance that the vessel will have to overcome a computer software named the Marine Book was developed using C sharp to analyse the calm water condition and

comparing it with sea state condition, it was concluded that the energy efficiency of a vessel can be improved by improving the engine but its improvement sometimes may not be so much felt due to the resistance a vessel must overcome, hence it is important to ensure that vessel total resistance is reduces to moderate level by considering metocean data for route selection in other for the engine to be more efficient and hence reduce emission level [16].

3.1. The Vessel Speed on Resistance Effect

A graph of the relationship between vessel speed and resistance is shown in Figure 4 below. The graph depicts that when ship speed increases at BN 5, vessel resistance increases.

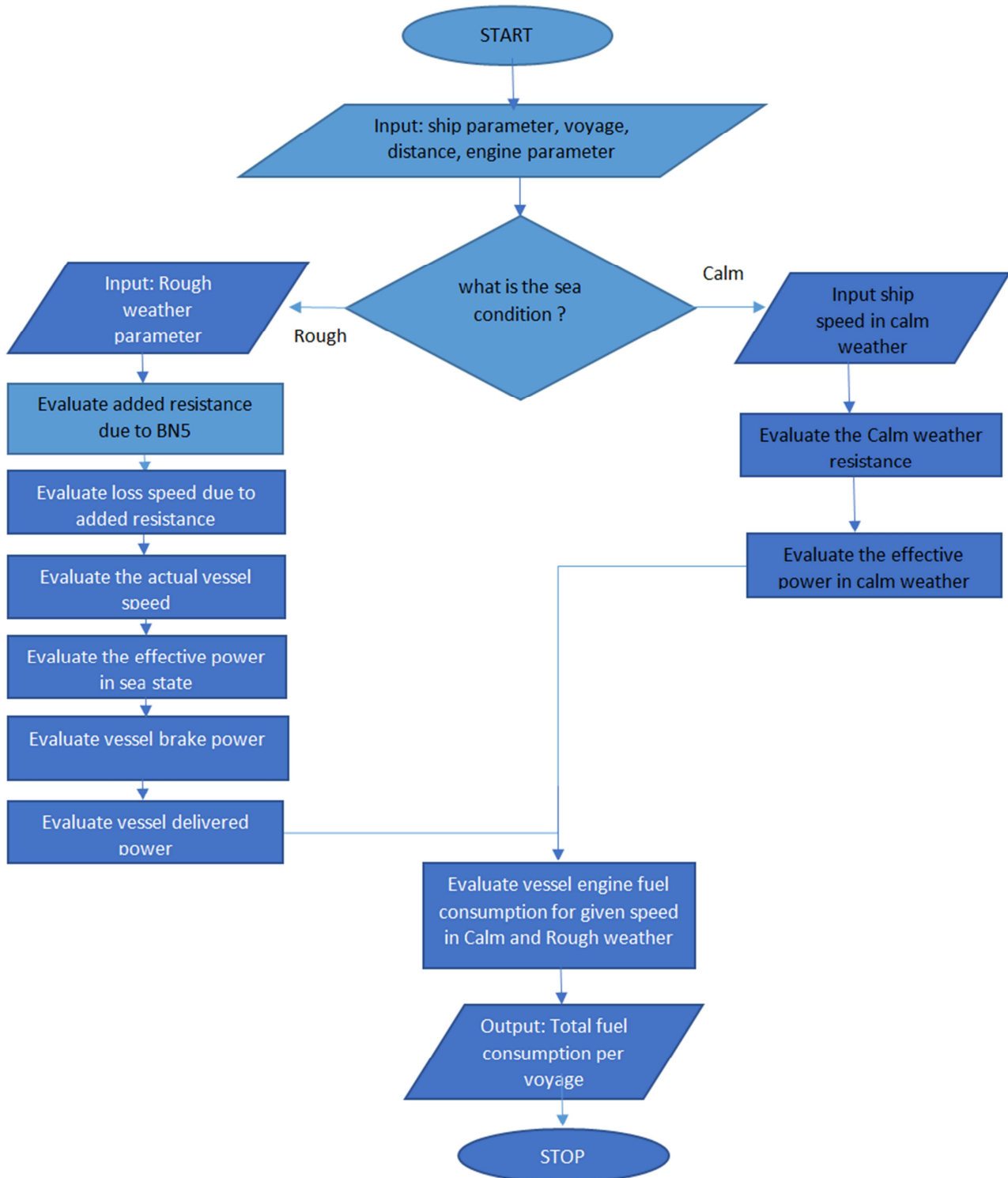


Figure 3. Flow chart depicting the fuel consumption during voyage.

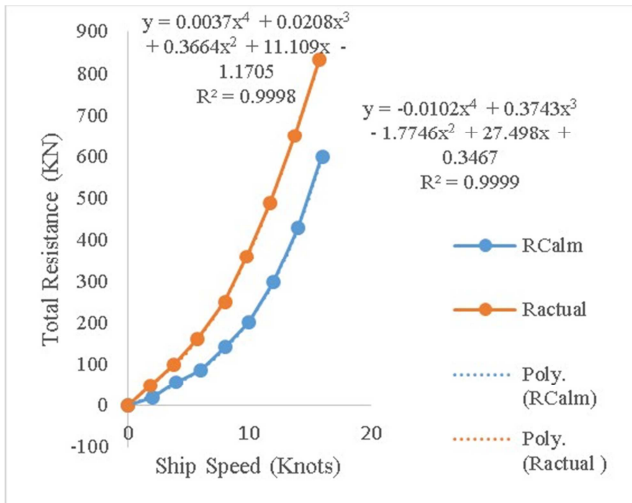


Figure 4. Ship Speed against Resistance.

From the graph above, it is seen that for every rise in fuel consumption which is due to increase in speed that there is a corresponding increase in the EEOI level since fuel consumption is in direction proportion to ship speed mathematically. Conventionally the smaller the EEOI level indicate a greater energy efficiency, so from the graph, at fuel consumption (FC) equal 103.63mt/2weeks having an EEOI level of 4.42×10^{-5} tCO_2/tnm is known to be more efficient than (FC) of 555.4.4mt/2weeks having the EEOI level of 7.80×10^{-5} tCO_2/tnm .

3.2. The Vessel Speed on Fuel consumption Effect

The graph from the figures 4 shows that a higher resistance is obtained when the vessel is operating on a sea state condition while lower ship resistance is obtained when operating vessel at calm water condition. According to the graph's regression equation, ship resistance increases in a sea state as opposed to a calm sea condition. Based on the investigation, a regression equation was created from the graph that can be used to calculate resistance for any given ship speed. The graph from figure 4 shows that for particular ship speed that there is corresponding increase in calm water resistance and about 5% more in a sea state.

3.3. The Vessel EEOI on Fuel Consumption Effect

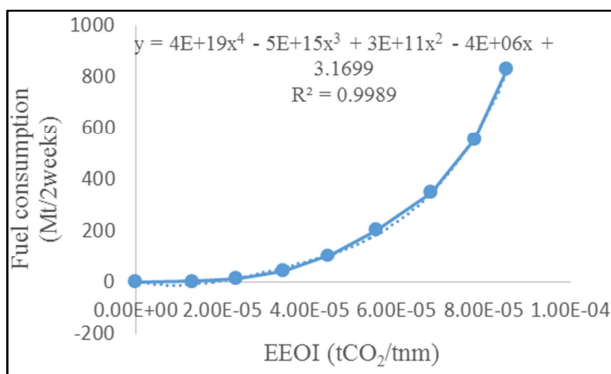


Figure 5. Vessel EEOI against Fuel Consumption.

The figure 5 above shows a graph depicting relation between the EEOI and vessel fuel consumption under a weather condition (BN5). The model is use to predict the energy efficiency operational indicator for every fuel quantity consumed during the ship voyage following the International Maritime Organization (IMO) regulation.

Figure 6 below shows a graph showing the relationship between vessel speed and fuel use. In ship operation fuel consumption increase as the vessel speed increase as to overcome increased resistance and maintain a given speed.

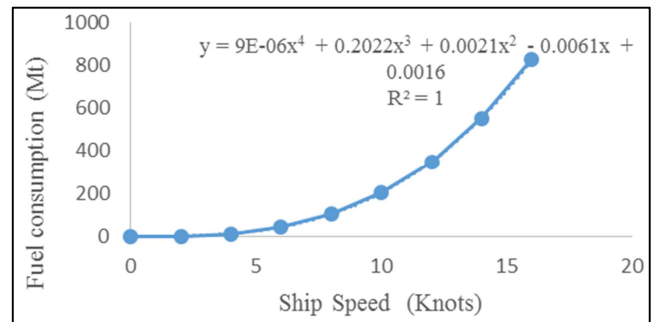


Figure 6. Vessel speed against fuel consumption.

For a vessel to maintain a given speed say 10knot in a weather condition (BN5), the vessel will use 202.4Mt/2weeks and 14.45Mt/day. Due to the increased propulsion, power required to overcome the increased ship resistance brought caused by the severe seas, there has been an increase in fuel consumption. For selection of sea state condition when the ship speed is reduces to say 8knot, it indicate a lower fuel consumption since ship speed is in direct propulsion with amount of fuel consumed. From the graph above considering the fact that more fuel is consumed at ship speed of 14.5knot, from the operational parameter of the study vessel it can be said that the economic speed for the vessel is calculated to be 12.18knot.

3.4. Effect of Mass of Cargo (Mcargo) to EEOI

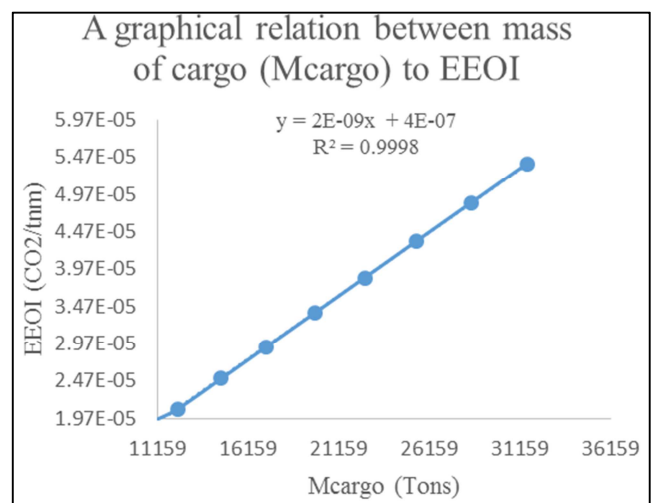


Figure 7. Mass of Cargo against EEOI.

The figure 7 above depict a graphical relation between mass of cargo (Mcargo) to EEOI. The simulation model was used to predict the EEOI values at different cargo weight.

The graph shows that EEOI value will increase as the cargo weight increase since the vessel consumes more fuel at higher cargo mass, in order to maintain the required ship speed more power is require and it is gotten from the combustion of more fuel at the combustion chamber, hence generating greater EEOI value. From the graph it can be seen that the vessel EEOI value is lowest at the point when the mass of the cargo is lowest, hence it can be concluded that at constant distance that increase in the cargo weight gives a corresponding increase in the EEOI value. For an increase in mass of the cargo requires a higher power, so for mass of cargo of 25453 will require more power as when compared to a mass of 16159 which has an EEOI of $2.47\text{E-}05\text{t.co}_2/\text{tnm}$ as to $4.348\text{E-}05\text{t.co}_2/\text{tnm}$.

4. Conclusion

The following conclusions are drawn from the analysis performed using the created program DMarine Book based on the anticipated outcome.

Total resistance decreases by around 159.1 KN when operating at a speed of 12.18 knots, indicating that the engine is operating in its fuel-economy zone, as compared to total resistance at rated speed of 14.5 knots (the ship's maximum continuous rating of the engine). This is seen to be in agreement with the established rule of ship resistance and speed increase in rough weather and in calm sea condition as established by other researchers.

When operating the ship at a cruising speed of say 12.18knot, that the overall fuel consumption reduces, which in turns reduces the energy efficiency operational indicator (EEOI) to about $3.290\text{E-}05\text{t.co}_2/\text{tnm}$, and hence reducing the CO₂ emission level in order to operate within the International Maritime Organization (IMO) limit.

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