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Research Article

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Modeling Energy Efficiency of Offshore Support Vessels (OSVs) Operating in Calm Weather Condition

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Abstract The global concerns for high cost of bunker fuel has led to accelerated research in improving ship energy management. In this work analytical and empirical methods were used in modeling hull resistance and fuel consumption of an offshore support vessels (OSV) operating from Onne port in Nigeria to Bonga Offshore field including standby period. A computer model - GrenMarine™ which uses Holtrop method to determine resistance and power was developed to predict the level of energy efficiency adopting energy efficient technologies. Operating the OSV at economical speed of 10 knots instead of the rated 15knotsunder calm weather condition resulted in a decrease of 10.7 % in resistance and a fuel saving of 13.4%. The results obtained are in good agreement with results obtained by other authors that used difference models under similar operating conditions. Calculation of the Energy Efficiency Design and Operational Indicators (EEDI & EEOI) as prescribed by International Maritime Organization (IMO) gave a decrease of 5%and 4.6%in EEOI and Carbon Dioxide (CO_2) emission respectively when mooring the vessel at a buoy in the offshore field was considered.

Keywords Energy-Efficiency, Offshore Mooring, Emissions, Fuel Cost-saving, GrenMarine™

1. Introduction

Shipping accounts for about 70% of international trade transportation and a significant single source of greenhouse gas (GHG) emissions which is known to be responsible for Climate change. Reduction of GHG to an acceptable level within the next decades requires conscious and deliberate efforts in implementing energy efficient measures in the shipping industry. CO_2 exhaust emissions from ships were estimated to be about 1046 million tons and about 2.7% of the global CO_2 exhaust emissions in 2007 were from international ships alone. IMO projected that this figure may likely triple by 2050 [1]. In response to this projection the organization introduced maritime energy efficiency regulation which became effective in January 2013 [2]. The objective was to decrease carbon emissions by reducing fuel consumption. The strategy adopted to achieve this, is by optimization of the ship's design, improving shipboard operations, upgrading shipboard equipment to meet up new technologies, and adopting new energy efficient technologies. The regulation stipulates that new and existing vessels above 400gross tonnage must have an approved Ship Energy Efficiency Management Plan (SEEMP) put in place [3]. As the desire for economical shipping management increases, a more conscious effort towards energy efficient operational measures is highly required.

Generally, marine engines fitted in commercial shipping use the cheaper type of 'bunker fuel' Intermediate or heavy fuel Oil (IHF or HFO). The cost of these intermediate fuel oils has risen sharply with other petroleum products. For example, IFO (180) increased from $170/t and $230/t in 2002 and 2005 respectively to nearly$700/t in July 2014 [4]. With such high fuel prices, the bunker fuel costs could account for 50–60% of a ship's total operating costs [5]. This paper thus, focuses on modeling energy efficiency in terms of EEOI and predicted CO_2 emission for offshore field support vessel when in operation and moored at a buoy.

The routes selection using Meteorological and Oceanographic (MetOcean) data in voyage optimization is another technology used in ship energy management. It is based on the evaluation of ship operational performance in each alternative route. The accuracy of the ocean weather forecast and the frequency of updating the forecast have a significant impact on voyage optimization process. However, for the energy saving in voyage the route considered is from Onne port to Bonga field using Metocean data [6]. The results obtained were used in the resistance and speed optimizations models.

2. Materials and Methods

Microsoft visual studio (C#) was used for the programming in combination with MS Excel and MS Access. A Computer program with code name GrenMarine[TM]was developed to predict the performance of the vessel during the voyage.Particulars of the Offshore Support vessel, main engine and generators are shown in Table 1.

Table 1: Particulars of Offshore vessel (SIEM MARLIN)

Parameter	Unit	Value
Length Overall	m	93.60
Length (LBP)	m	86.60
Breadth Moulded	m	19.70
Depth Main Deck	m	7.85
Max. Load Line Draft Midship	m	6.30
Deadweight	Tonnes	4213
Rated Speed	Knots	15
Propellers	Two(2) Azipull azimuth thrusters	Power: (2,200kW), 1800rpm
Main generators (Caterpillar 3516)	Four (4) , 2100eKW, 1800rpm,	
Auxiliary generator (Caterpillar C18)	Two(2), 550ekw, 1800rpm	
Emergency generator (Caterpillar C9)	One (1), 185eKW, 1800rpm	

Mathematical Model

A statistical and re-analysis of resistance and propulsion data Holtrop[7] were used to model the resistance of the vessel under calm water condition and at weather (BN4). The data provide prediction of the total resistance of wide varieties of ship sizes, hull forms and range of Froude numbers.

The total resistance is expressed as:

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

Where:

- R_T Total ship resistance in calm water (kN)
- R_F Frictional resistance (kN) according to the IITC – 1957 friction formula $(1+K_1)$ Form factor
- R_{APP} Appendages resistance (kN)
- R_W Wave making and wave breaking resistance (kN)
- R_B Additional pressure resistance of bulbous bow near the water surface (kN)
- R_{TR} Additional pressure resistance of immersed transom stern (kN)
- R_A Ship correlation resistance (kN)

Added resistance was estimated using Kwon's predict the % of speed loss as:

$$V_L = \alpha_{Corr} * \mu_{red} * \frac{\Delta V}{V} 100\% \qquad (2)$$

Where

α_{Corr} Speed reduction coefficient
μ_{red} Weather direction reduction coefficient

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

and

$$C_{\mu} = \alpha_{corr}$$
$$C_{form} = \text{Ship form coefficient}$$

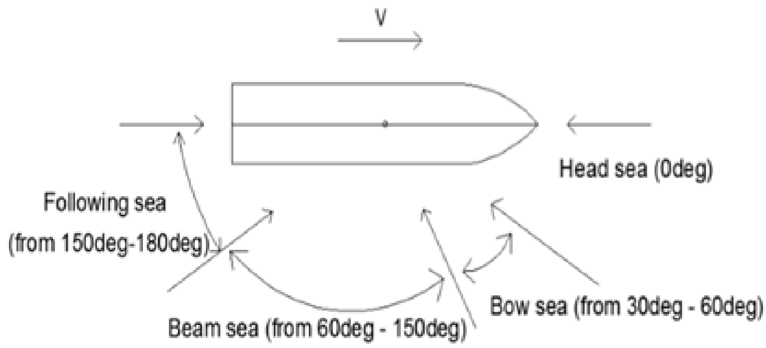

Figure 1: Ship direction of weather effect [8]

Figure 1 shows an illustration of ship direction in relation to weather direction. The various angles (in degree) indicated were considered in the model.

Energy Saving during standby

Total fuel consumption per month during standby time (F_{wt}) is given by[9]:

$$F_{wt} = F_{ah} * T_{wm} \quad (4)$$

Where

F_{ah} Average vessel fuel consumption per hour (m^3)
T_{wm} Total standby time per month (hour)

The prediction of energy saving during standby period was carried out using the three (3) months operational period. Tables 2 and 3 show the data.

Table 2: Total Fuel Consumption

S/N	Month	Vessel Fuel Consumption (mt/month)	Fuel Consumption (mt/day)	Fuel Consumption (mt/hour)
1.	June	206.66	6.89	0.28
2.	July	250.26	8.08	0.34
3.	August	172.602	5.56	0.23
Average		244.00	7.96	0.33

Table 3: Total Standby Time

S/N	Month	Duration (Hr: Min: Sec)	Duration (Hour)
1.	June	159:30:00	159.50
2.	July	229:06:00	229.10
3.	August	133:24:00	133.40
	Total	521:60:00	522.00

Energy Efficiency Operational Indicator (EEOI)

EEOI, (former operational CO_2 –index), is an IMO initiated measuring tool for the CO_2 gas emission to the environment per the transport work in shipping. It is a representation of a ship's actual transport efficiency when in operation.

EEOI is given by [1]:

$$EEOI = \frac{\sum FC_i * CF_j}{m_{cargo} * D} \quad (5)$$

For several voyages, the indicator is expressed as an average and is given by:

$$Average\ EEOI = \frac{\sum_i \sum_j (FC_{ij} * CF_j)}{\sum_i (m_{cargo} * D_i)} \quad (6)$$

Where;

j fuel type;

I voyage number;

FC ij mass of consumed fuel *j* at voyage *I*;

CFj fuel mass to CO_2 mass conversion factor for fuel *j*;

m_{cargo} mass of cargo

D distance in nautical miles corresponding to the cargo carried.

Flow charts used for modeling vessel fuel consumption in voyage and during standby are shown in figures 2 and 3 respectively.

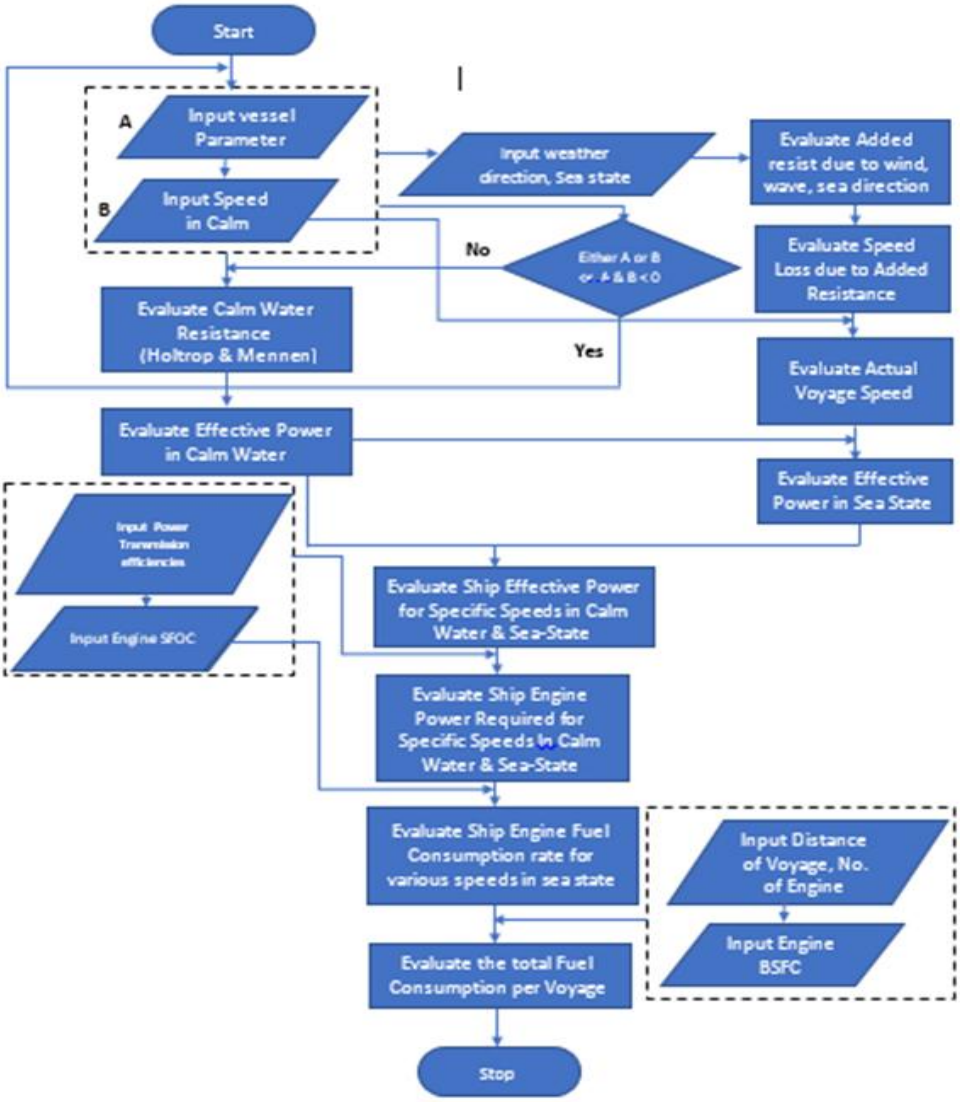

Figure 2: Flow Chart for Fuel Consumption in voyage

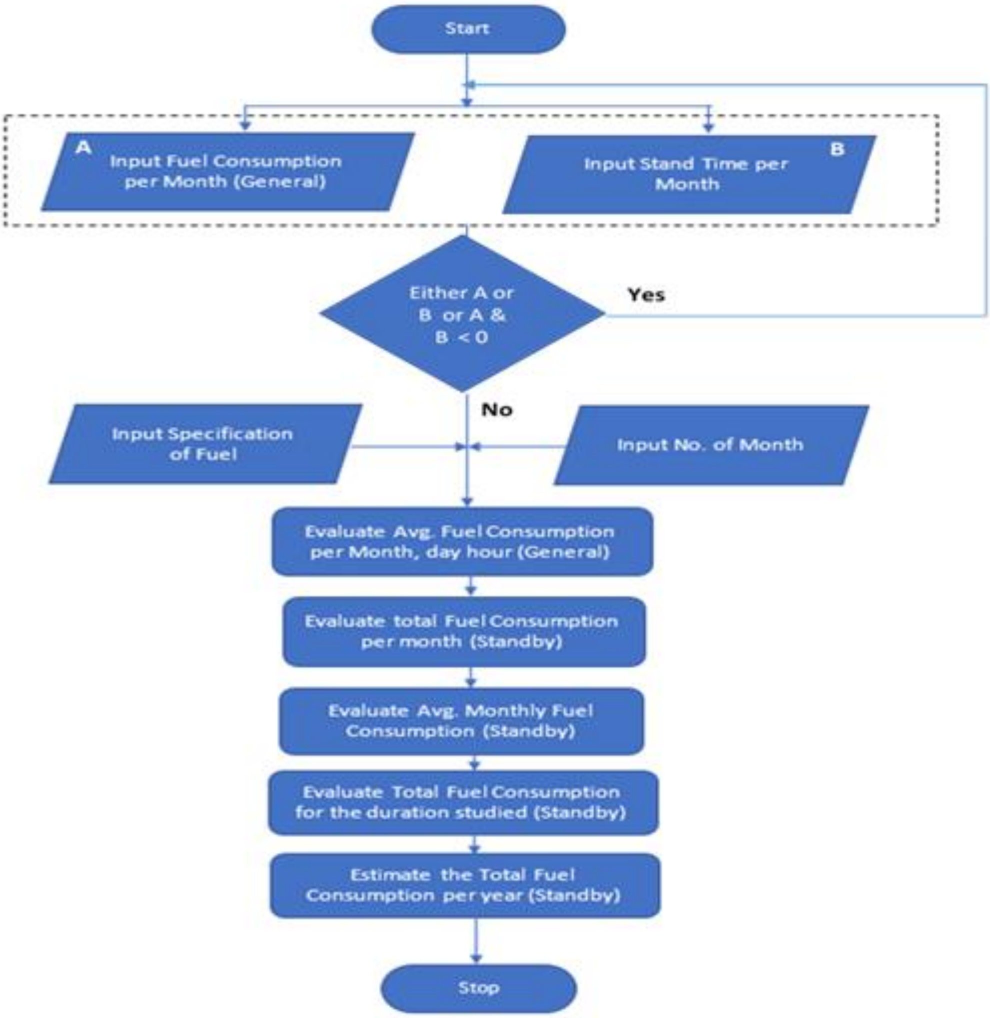

Figure 3: Flow Chart for Fuel Consumption during standby

3. Results and Discussion

Effect of Vessel Speed on Resistance

Figure 4 shows the graphical relation between vessel speed and resistance. The graph clearly shows the exponential increase in resistance with increasing vessel speed.

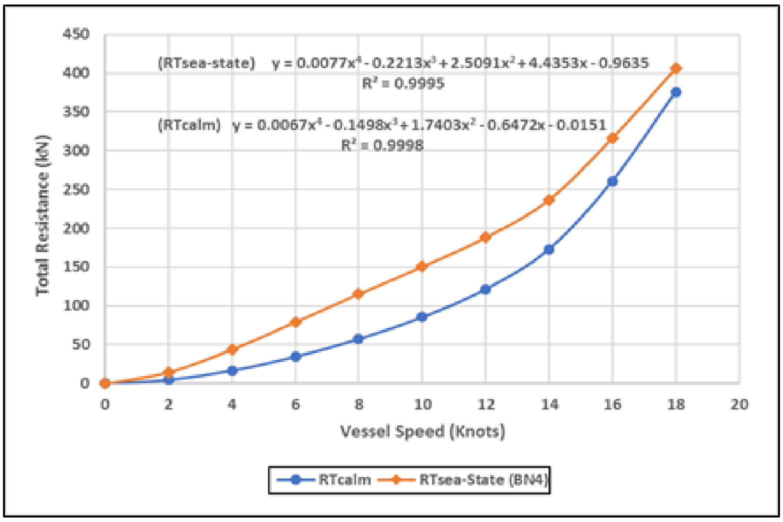

Figure 4: Speed versus Resistance diagram for OSV

At BN 4, 10% reduction in speed (i.e. from 11knot to 10knot) shows11% decrease in resistance whereas in calm water, 10% reduction in speed decreases the resistance by 16.29%. Thegraph shows that resistance increases at sea state of BN 4 compared to calm sea. The developed regression equations (shown on the graphs) are based on the analysis and may be used to estimate resistance for any given speed of the vessel in calm water and in rough sea state.

Effect of Vessel Speed on Fuel Consumption

Figure 5 shows the relations between speed of the vessel and fuel consumption in kilogram/hour (kg/hr). From GrenMarine™ prediction, increase in speed shows an exponential increase in fuel consumption.

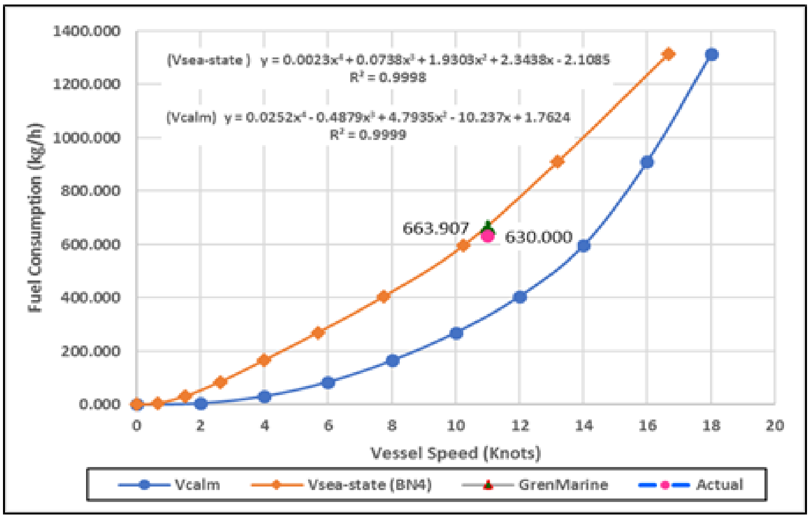

Figure 5: Speed versus Fuel Consumption for OSV

The difference between Vcalm and Vsea-state (BN4) was as a result of the increase in power requirement to overcome added resistance such as to maintain a given speed. To maintain speed of 11knot (i.e. 75% rated vessel speed)in weather condition (BN4), the vessel consumes additional 297kg/hr (i.e. 47%) of fuel. Increase in fuel consumption is as a result of the needed increase in propulsion power to overcome the increased resistance due to the rough sea state. In the selected sea state, if the speed is reduced to 10knots (i.e. approximately 10%), the fuel consumption reduces by89kg/hr, hence, giving 13.4% fuel saving. However, the trend of the graphs and the percentage saving are consistent with established trends and saving potential respectively.

Relationship between Vessel Speed and EEOI

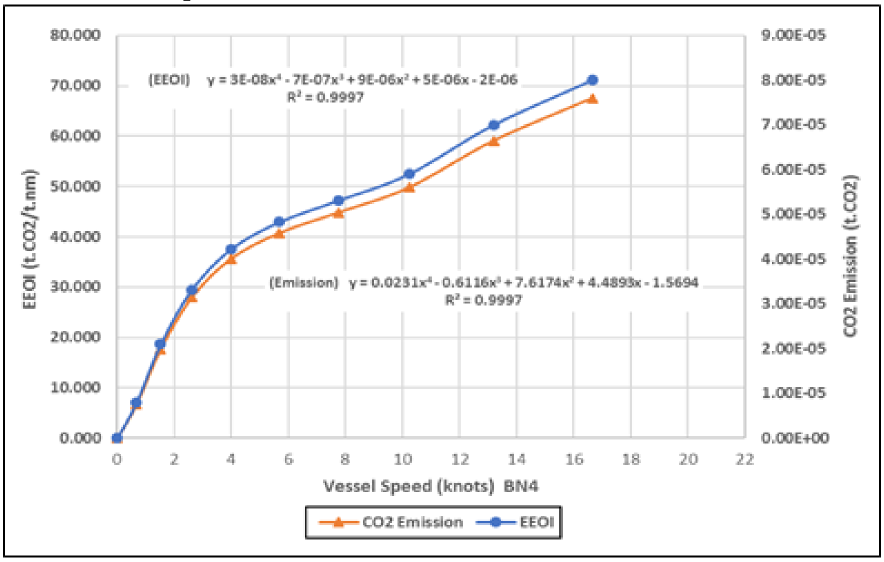

Figure 6: Vessel speed versus EEOI and CO_2 Emission diagram

Figure 6 shows the graphical relation between vessel speed, EEOI and CO_2emission under the selected weather condition(BN4). GrenMarine^{TM} was used to predict energy efficiency of OSV which was predicted following IMO regulation. The relationship between EEOI, emission and speed of the vessel as predicted by the software is shown in figure 6. It could be observed that both EEOI and CO_2 emission follow the same trend. This is expected because mathematically, EEOI is directly proportional to fuel consumption. It could also be seen that as the speed of the vessel increases, EEOI and CO_2 emission also increased. Conventionally, smaller EEOI indicates greater energy efficiency. At 75% of the rated speed for OSV, the EEOI and emission are 6.12E-05t.CO_2/t.nm and 51.647t.CO_2 respectively. If the speed is reduced to the economy speed of 10knots, EEOI and the emission would reduce by2.82E-06t.CO_2/t.nm(i.e. 4.6%)and 2.377t.CO_2(i.e. 4.6%) respectively.

4. Conclusions

Based on the analysis carried out and the predicted results using GrenMarine^{TM} the following conclusions are made:

- Comparing total resistance at75% rated speed of 15 knots (the maximum continuous rating of the engine), and at 10 knot (cruising engine speed), the total resistance decreased by16.64kN (16.29%).This was as a result of the engine operating in the fuel economy zone. This conforms to established results of vessel resistance and speed increase in calm and rough weathers established by other investigators. However, the model GrenMarine^{TM} used in this work gave a better repeatability of results when compared with the actual fuel measurement made by the crew during the operational period investigated.
- At vessel speed of 10 knot fuel consumption reduced, energy efficiency improvement of the voyage in terms of EEOI which gave a reduction of 4.6% CO_2.
- The use of mooring buoy for the OSV during standby period offered saving in cost of fuel consumed for propulsion and reduction in emission.

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