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# POSSIBILITY OF $CO_2$ EMISSION REDUCTION FROM INLAND OIL TANKERS BASED ON REVISED EEDI PARAMETERS

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## ABSTRACT

Though inland ships share a small portion of the total global $CO_2$ emission from shipping, from the individual country's economic and environmental perspective, this is very important. In order to reduce $CO_2$ emission from the sea going ships by increasing energy efficiency, International Maritime Organization (IMO) adopted a generalized Energy Efficiency Design Index (EEDI) in 2011. However, due to the variation in the environmental, geographic and economic conditions, a generalized EEDI cannot be established in a similar fashion as established by IMO. Shallow and restricted water effects, different fuel qualities (to reduce operational cost), increase in engine power requirement, reduction in carrying capacity, cargo availability, etc. forbid the use of existing EEDI formulation for inland waterways. So, an EEDI formulation based on revised parameters has been proposed for the inland ships of Bangladesh. This paper focuses on the implementation of the revised EEDI formulation by performing a sensitivity analysis of different ship design parameters. Based on the analysis, suggestions were made on how to design inland oil tankers of Bangladesh using the revised EEDI formulation for reducing $CO_2$ from the current level. Keeping the same speed and capacity, those vessels were redesigned based on those suggestions. The CFD analysis of those redesigned vessels using 'Shipflow' has shown a total resistance reduction of 10-13%.

*Keywords*: EEDI, $EEDI_{INLAND}$, $EEDI_{IMO}$, Inland Oil Tanker, $CO_2$ emission, Energy Efficiency, MEPC

## 1 INTRODUCTION

The adopted EEDI formulation by IMO [1] to increase the energy efficiency of sea-going ships is successful so far [2]. However, IMO does not have any guideline for inland ships in EEDI regulations yet. The absence of appropriate energy and emissions benchmark for Inland Waterway Self-Propelled ships is a large impediment to performance improvements of inland ships [3]. Inland ships, in general, require more power at the same speed in comparison to similar type open water/seagoing ships [4]. Figure 1 shows the $CO_2$ emission per transport unit (tonne-km), where different freight transport modes (Road, Rail, Maritime and Inland Shipping) over the period of 1995 to 2009 in Europe are presented [5]. From Figure 1, it is evident that $CO_2$ emission from inland ships is more than double over other maritime transport.

By definition, EEDI by IMO (Hence denoted as $EEDI_{IMO}$) quantifies the transport work for estimating the amount of $CO_2$ emission by sea-going ships [6]. The prime focus of this paper is inland oil tankers of Bangladesh. EEDI for inland oil tankers of Bangladesh will quantify the same, however, the EEDI parameters needs to be revised. For example, the effect of shallow water must be incorporated for EEDI for inland oil tankers of Bangladesh. In addition, the consideration for speed and engine power to be used in the calculation should be revised. Another important factor is the carbon content of the fuel. Due to the addition of impurities in the fuel used in the inland shipping of Bangladesh, the carbon content of fuel needs to be determined accurately.

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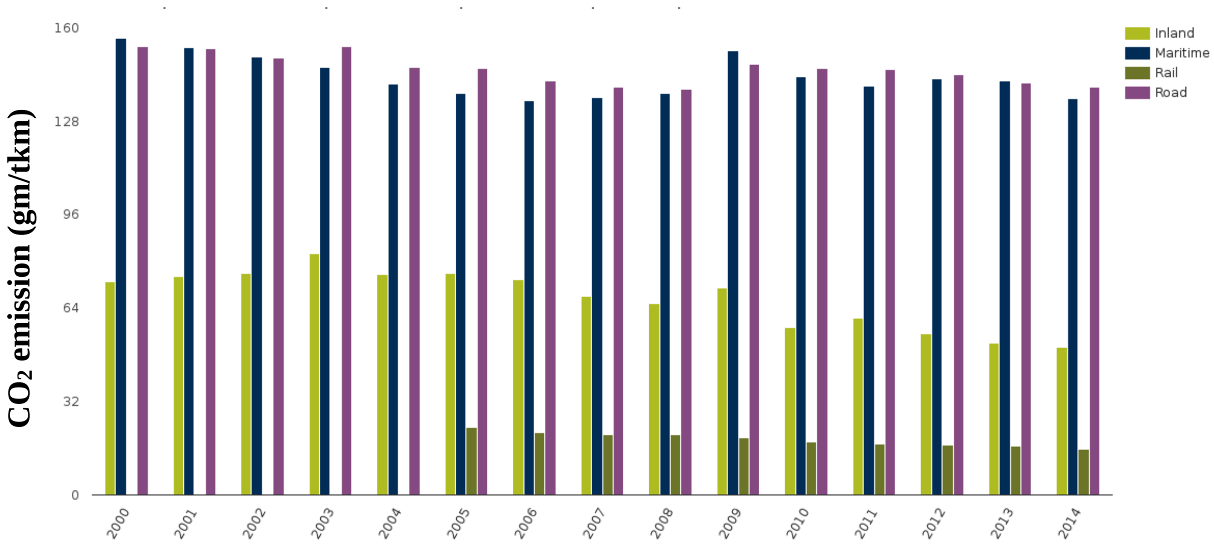


Figure 1. Specific $CO_2$ emissions per tonne-km and per mode of transport in Europe [5].

Considering the above factors, Hasan and Karim [6] had proposed revised EEDI parameters for inland ships of Bangladesh. In this paper, EEDI values of 251 number of existing inland oil tanker of Bangladesh have been calculated using the revised formulation. All vessels have been categorized into 3 segments, based on their length and EEDI values. Because of the discretization, efficient ranges of different ship design parameters were identified.

It is very interesting to implement the newly found efficient ranges of ship design parameter on the most efficient oil tanker of each range. Total resistance for both the existing and revised ship models have been calculated using CFD software 'Shipflow.' For fare comparison of existing and redesigned ship, capacity and service speed have been kept same as existing one.

## 2 BREIF DESCRIPTION OF EEDI BY IMO

EEDI in its simplest form can be expressed as follows [7]:

$$\text{EEDI}=\frac{\mathrm{CO_2 Emission}}{\text{Transport work}}$$

$$=\frac{\text{Power} * \text{Specific fuel consumption} * \mathrm{CO_2}\text{conversion factor}}{\text{Factors} * \text{Capacity} * \text{Speed}}$$

$$=\frac{\begin{gathered}\text{Emission from Main Engine} + \text{Emission from Auxiliary Engine} + \text{Emission for running shaft motor}\\ -\text{Efficient Tech. Reduction}\end{gathered}}{\text{Different factors} * \text{Capacity} * \text{Reference Speed}}$$

$$=\frac{\begin{gathered}(\Pi_{j=1}^{n} f_j)(\Sigma_{i=1}^{nME} P_{ME(i)}.C_{FME(i)}.SFC_{ME(i)})++(P_{AE}.C_{FAE}.SFC_{AE})+\\ \left(\Pi_{j=1}^{n} f_j.\Sigma_{i=1}^{nPTI} P_{PTI(i)}-\Sigma_{i=1}^{neff} f_{eff(i)}.P_{AEeff(i)}\right)C_{FAE}.SFC_{AE}-(\Sigma_{i=1}^{neff} f_{eff(i)}.P_{eff(i)}.C_{FME}*SFC_{ME})\end{gathered}}{f_i.f_c f_l*\text{Capacity}*V_{ref}*f_w} \quad (1)$$

$$=\frac{kw*\frac{g_{fuel}}{kwh}*\frac{g_{CO2}}{g_{fuel}}}{\text{Tonne}*\text{knotical mile/h}}$$

$$=\frac{g_{CO2}}{\text{Tonne}*\text{knotical mile}}$$

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Equation (1) of EEDI contains different constants and coefficients which are briefly described in following Table 1:

Table 1. Description of different parameters of EED by IMO [7]

| Parameter | Description |
|---|---|
| $f_j$ | Correction factor to account for ship specific design elements. (For e.g. ice classed ships, shuttle tankers) |
| $P_{ME}$ | 75% of the main engine MCR (Maximum Continuous Rating) in kW |
| $C_{FME}$ and $C_{FAE}$ | Non-dimensional conversion factor for main engine between fuel consumption measured in gram and $CO_2$ emission also measured in gram on carbon content. ME and AE stands for main and auxiliary engine, accordingly. |
| $SFC_{ME}$ | Certified Specific Fuel Consumption of main engine in g/kWh |
| $P_{AE}$ | Auxiliary Engine Power |
| $SFC_{AE}$ | Certified Specific Fuel Consumption of main engine in g/kWh |
| $P_{PT(i)}$ | 75% of rated power consumption of shaft motor |
| $f_{eff(i)}$ | Availability factor of innovative energy efficiency technology |
| $P_{AEeff(i)}$ | Auxiliary power reduction due to innovative electrical energy efficient technology |
| $P_{eff(i)}$ | Output of innovative mechanical energy efficient technology for propulsion at 75% main engine power |
| $f_i$ | Correction factor to account for ship specific design elements. (For e.g. ice classed ships, shuttle tankers) |
| $f_c$ | Cubic capacity correction factor (for chemical tankers and gas carriers) |
| $f_l$ | Factor for oil tanker ships equipped with cranes and other cargo related gear to compensate in a loss of deadweight of the ship |
| Capacity | Oil Tanker: Computed as a function of Deadweight as indicated in 2.3 and 2.4 of MEPC 245(66) “2014 Guidelines on the calculation of the Attained EEDI for new ships” |
| $f_w$ | Non-dimensional coefficient indicating the decrease of speed in representative sea condition of wave height, wave frequency and wind speed |
| $V_{ref}$ | Ship speed in nautical miles per hour at $P_{ME}$ |

## 3 REVISED EEDI PARAMETERS FOR INLAND SHIPS OF BANGLADESH

There are several reasons for proposed EEDI revision by Hasan and Karim [6]. Deviations from original EEDI formulation of IMO are to be considered to achieve the exact scenario of the $CO_2$ emission level for the inland shipping of Bangladesh. Prime reasons and modifications are shown in Table 2.

Table 2. Comparison of EEDI parameters as defined by IMO and revised for Bangladesh

| Sl. | $EEDI_{IMO}$ Parameter | Defined by IMO [7] | Reason for the revision | Revised value for inland oil takner of Bangladesh |
|---|---|---|---|---|
| 1 | $P_{ME}$ | 75% of the main engine MCR in kW | Investigation has shown that average MCR for the inland oil tankers of Bangladesh is 60%, considering shallow water and other economic effects [6]. | 60% of the main engine MCR in kW |
| 2 | $V_{REF}$ | Ship speed in nautical miles per | As per the definition of IMO, speed at $P_{ME}$ is the $V_{REF}$. Moreover, speed | Ship speed in nautical miles per hour at $P_{ME}$ (at 60% MCR) |

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| | | | | |
|---|---|---|---|---|
| | | hour at $P_{ME}$ (at 75% MCR) | from due to the shallow water effect must be incorporated. | |
| 3 | Capacity | Computed as a function of dead weight | 100% dead weight as per IMO but 85% as investigated by Hasan and Karim [6]. | 85% of the total design dead weight. |
| 4 | Carbon Content of Diesel oil | 0.87441 | Refined diesel having lower Carbon Residue, Ash and Sediment are used in Bangladesh [6]. | 0.76 as per the test result [6]. |
| 5 | $C_F$ (non-dimensional $CO_2$conversion factor) | $C_F$(IMO): Carbon Content in the fuel X (Molecular weight of $CO_2$/Molecular weight of Carbon) = 0.8744 X (44/12) = 3.206 gm $CO_2$/gm fuel | As per the new carbon content value. | $C_F$ (Inland ships of Bangladesh): Carbon Content in the fuel X (Molecular weight of $CO_2$/Molecular weight of Carbon) = 0.76 X (44/12) = 2.787 gm $CO_2$/gm fuel |

## 4 IMPLEMENTING PROPOSED EEDI

The proposed revised EEDI formulation has been implemented on 102 numbers inland oil tankers of Bangladesh. Those results were further divided into three categories, based on their length and EEDI value.

- 'Group-1' consists of ships having length below 51.00 meter.
- 'Group-2' consists of ships having length ranging between 51.00-61.00 meter.
- 'Group-3' consists of ships having length above of 61.00 meter.

For each group, major ship design particulars have been presented in Table 3-5.

Table 3: Ship design particulars of oil tanker from Group-1 [Total number of ships: 23]

| Ship Design Particulars | Vessel Length up to 51.00 meters | | | Vessel Length up to 51.00 meters | | |
|---|---|---|---|---|---|---|
| | Well performing vessel's ranges | | | Poor performing vessel's ranges | | |
| | Min | Max | Average | Min | Max | Average |
| Length/Beam | 4.47 | 5.90 | 4.82 | 4.00 | 5.62 | 4.79 |
| Beam/Draft | 2.44 | 5.26 | 3.79 | 2.38 | 5.93 | 4.03 |
| DWT/Displacement | 0.59 | 0.76 | 0.67 | 0.52 | 0.69 | 0.62 |
| Ship Speed (Knot) | 7.50 | 9.00 | 8.63 | 6.00 | 9.00 | 8.00 |
| Froude Number ($F_N$) | 0.18 | 9.00 | 0.207 | 0.18 | 0.25 | 0.214 |
| Block Coefficient ($C_B$) | 0.73 | 0.85 | 0.79 | 0.51 | 0.81 | 0.74 |
| EEDI | 25.70 | 30.07 | 27.99 | 31.89 | 63.42 | 37.61 |

Table 4: Ship design particulars of oil tanker from Group-2 [Total number of ships: 39]

| Ship Design Particulars | Vessel Length 51.00-61.00 meters | Vessel Length 51.00-61.00 meters |
|---|---|---|
| | Well performing vessel's ranges | Poor performing vessel's ranges |

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| | Min | Max | Average | Min | Max | Average |
|---|---|---|---|---|---|---|
| Length/Beam | 4.82 | 6.03 | 5.25 | 4.82 | 6.37 | 5.28 |
| Beam/Draft | 1.80 | 6.11 | 3.15 | 2.45 | 6.11 | 4.17 |
| DWT/Displacement | 0.57 | 0.77 | 0.67 | 0.57 | 0.68 | 0.64 |
| Ship Speed (Knot) | 8.00 | 9.00 | 8.73 | 8.00 | 10.00 | 8.85 |
| Froude Number ($F_N$) | 0.17 | 0.21 | 0.190 | 0.17 | 0.21 | 0.195 |
| Block Coefficient (CB) | 0.65 | 0.79 | 0.77 | 0.64 | 0.79 | 0.75 |
| EEDI | 21.58 | 25.65 | 23.84 | 26.18 | 32.79 | 29.20 |

Table 5: Ship design particulars of oil tanker from Group-3 [Total number of ships: 40]

| Ship Design Particulars | Vessel Length above 61 meters | | | Vessel Length above 61 meters | | |
|---|---|---|---|---|---|---|
| | Well performing vessel's ranges | | | Poor performing vessel's ranges | | |
| | Min | Max | Average | Min | Max | Average |
| Length/Beam | 5.29 | 6.29 | 5.75 | 5.50 | 6.73 | 6.21 |
| Beam/Draft | 2.50 | 3.30 | 2.99 | 2.14 | 2.89 | 2.65 |
| DWT/Displacement | 0.62 | 0.70 | 0.64 | 0.58 | 0.66 | 0.63 |
| Ship Speed (Knot) | 9.00 | 10.50 | 9.65 | 9.50 | 12.00 | 9.97 |
| Froude Number ($F_N$) | 0.18 | 0.22 | 0.19 | 0.19 | 0.26 | 0.20 |
| Block Coefficient ($C_B$) | 0.69 | 0.81 | 0.76 | 0.65 | 0.80 | 0.72 |
| EEDI | 20.91 | 28.94 | 23.46 | 24.05 | 27.11 | 25.36 |

## 5 SENSITIVITY ANALYSIS

A ship's performance is a combined performance of all her design particulars. However, to improve the energy efficiency of a ship in light of EEDI, the value of Equation 1 should be the lowest. Tables 3 to 5 of Section 4 present the ranges of different ship design parameter for well performed vessels to poor performed ones. Sensitivity analysis has found the following results:

- The EEDI is particularly sensitive to the service speed, as the required power increases by roughly the cube of the variation in service speed ($P \propto V^3$) [8]. Reducing service speed by one knot reduces the EEDI by between 10% and 15% [9].

- Increase in lightweight has a relatively modest impact on the EEDI. Sensitivity analysis has shown for oil tankers that a 5% increase in hull steel weight increases the attained index by between 0.5%-2%.

- Readjustment of principal particulars and coefficients of inland ships of Bangladesh would reduce attained EEDI below the proposed baseline in most of the cases.

- The vessels, which cannot be optimized by the readjustment of principal particulars and coefficients, speed reduction is the only solution if any innovative design optimization or $CO_2$ reduction measure is adopted.

Based on the ranges of ship design particulars as presented in Table 3 to 5, followings suggestion can be made to have better ship design for inland ship of Bangladesh in terms of EEDI.

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**Table 6: Ship Design suggestion based on sensitivity analysis.**

| Ship Design Particulars | Decision to be taken |
|---|---|
| Water Line Length ($L_{WL}$) | Length of the vessel should be as minimum as possible to have the required displacement and surface area. The prime reason behind the decision is, increase of ship length will increase surface area of the ship, which eventually increase the frictional resistance. |
| Length/Breadth ($L_{WL}$/B) | Increasing L/B ratio is recommended. This will make the ship slender which will decrease wave resistance. However, it should be done decreasing the breadth and fulfilling all types of stability criteria. |
| B/T | Decreasing B/T ratio is recommended. This should be done by decreasing breadth, which eventually increases L/B ratio, helping in reduction of wave resistance. For inland ships, because of the draft restriction, maximum achievable draft should be used to achieve required displacement. |
| DWT/Displacement | High DWT/Displacement is desirable. Higher dead weight capacity for a fixed displacement will have increase the value of denominator, which will decrease EEDI. On the other hand, decrease in displacement for a fixed dead weight capacity, will have lower surface area. As a result, frictional resistance will be decreased and required main engine power will be less. This will decrease the numerator of the EEDI equation, which will decrease EEDI. |
| Block Coefficient ($C_B$) | A lower $C_B$ will ensure a sharp ship hull which is preferable for a ship to have low resistance. However, this coefficient is connected with displacement of the hull and the carrying capacity. Therefore, minimum $C_B$ to achieve the desired displacement is recommended. |
| Ship Speed (V) and Froude number ($F_N$) | Low Froude number is recommended. As, minimum length is recommended to have lower surface area, lowering the speed would be the best solution to reduce Froude Number and EEDI. It should be noted that, in the EEDI equation, speed is at the denominator. Lowering the speed should increase EEDI. However, since the required power increases by roughly the cube of the variation in speed[8], reduction in speed reduces power requirement (numerator of EEDI equation) and EEDI to a great extent. |

### 5.1 CFD analysis of improved vessel based on suggestion from sensitivity analysis

Improvements in the EEDI of 10% is possible for inland oil tankers of Bangladesh by adjusting ship design as per the suggestion made in Table 6. However, these improvements in the EEDI may come at a price. Followings are the example:

- A slender ship, having higher L/B ratio will give better performance in terms of power consumption. Hence increasing L/B ratio will lower EEDI. Increase of L/B ratio can be done by either increasing length or decreasing breadth or doing both. However, increasing length will increase wetted surface area, which will increase frictional resistance. This is not desirable for better energy efficiency of ship. In addition to that, for inland ships, Bangladesh has a restriction on length. Therefore, decreasing breadth to increase L/B ratio will solve the problem.

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- However, decrease in breadth will decrease total displacement and thus decrease the dead weight capacity. Decrease in dead weight capacity has a negative impact on EEDI value. On the other hand, decrease in breadth has huge impact on stability and all stability criteria must be satisfied before EEDI calculation.

- By increasing Block Coefficient ($C_B$) may solve all the above problems. 1% increase of $C_B$ increases the construction cost only 0.2%, it will increase the dead weight capacity by approximately 1% as well (Parsons, 2003). Higher dead weight capacity will definitely improve EEDI value for the ship.

- However, increasing the Block Coefficient will increase resistance by making the ship hull blunt. It will increase the power requirement and EEDI as well.

As discussed above, individual ship design parameters have individual impacts EEDI. It means changing the ship design particulars and ratio have both negative and positive impact on EEDI value. The prime reason is that, EEDI actually calculates the 'Benefit to the Society' at the 'Environmental Cost'.

Therefore, selection of initial ship design parameters based on the sensitivity analysis result shown in Table 6 should go under a holistic impact analysis on EEDI. This will find the best ship design with the lowest EEDI. In Tables 7 to 9, holistic approach on one of the best performed ship from each range (as found in Section 4.4.1-4.4.3) has been implemented. Later, the parent design and optimized design were further analyzed using a commercial Computational Fluid Dynamics (CFD) software called 'Shipflow'. For fare comparison, displacement, dead weight and speed for both parent and improved ship kept same. The test results are shown in Tables 7 to 9 and Figures 2 to 10.

**Table 7: Comparison between parent and improved oil tanker under Group-1**

| | Parent Design | Improved Design | Change (%) |
|---|---|---|---|
| Water line length, $L_{WL}$ (meter) | 49.73 | 55 | 10.60% |
| Moulded Breadth, $B_{MLD}$ (meter) | 10.13 | 10 | -1.28% |
| $L_{WL}/B_{MLD}$ | 4.91 | 5.5 | 12.03% |
| Loaded Draft, T(meter) | 3.04 | 3.34 | 9.87% |
| $B_{MLD}/T$ | 3.33 | 2.99 | -10.15% |
| Block Coefficient, $C_B$ | 0.72 | 0.6 | -16.63% |
| Displacement (Tonne) | 1102 | 1102 | 0.0% |
| Dead Weight (Tonne) | 733 | 733 | 0.0% |
| Speed (Knot) | 09 | 09 | 0.0% |
| Froude Number, $F_N$ | 0.21 | 0.2 | -4.91% |
| $EEDI_{BD}$ (gram/tonne.mile) | 23.04 | 19.89 | -13.65% |
| Surface Area, S ($m^2$) | 625.69 | 646.44 | 3.32% |
| Frictional Resistance Coefficient, $C_F$ | 0.00168 | 0.00181 | 8.05% |
| Wave Resistance Coefficient, $C_W$ | 0.00147 | 0.00115 | -21.88% |
| Total Resistance Coefficient, $C_T$ | 0.00406 | 0.00374 | -7.95% |

As shown in Tables 7, 12.03% L/B ratio of vessel from Group 1 was increased by increasing 10.60% length and decreasing 1.28% breadth. Increase in length increased the surface area by 3.32% which has increased frictional resistance by 3.32%. However, increasing length and decrease in the block coefficient by 16.63% has made the ship slender. As a result, wave resistance has decreased by 21.88%

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and overall, 7.95% decrease of resistance and 13.65% energy efficiency have been achieved without sacrificing the dead weight capacity or speed.

| Parent Hull | Improved Hull |
|---|---|

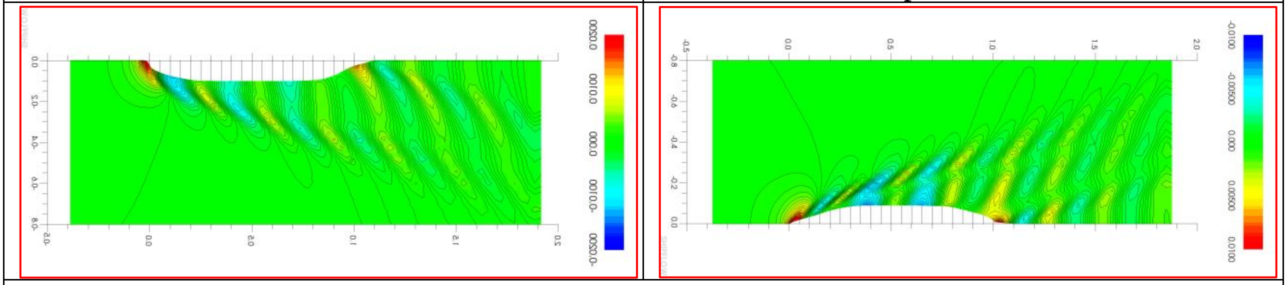

Figure 2: Free surface wave of vessel from Group 1

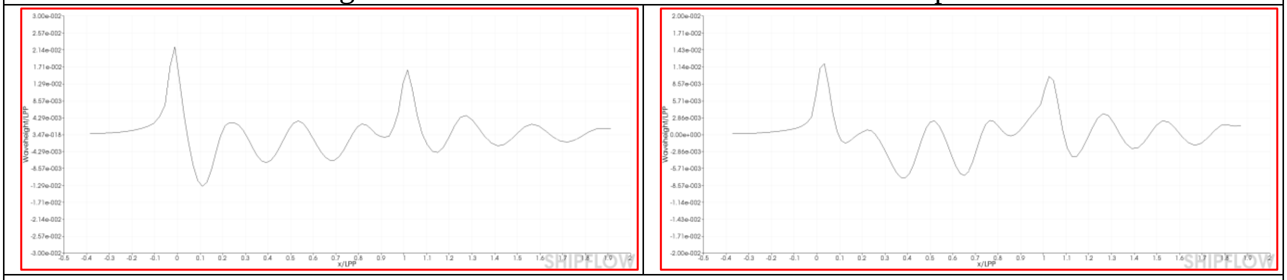

Figure 3: Wave height along hull of vessel from Group 1

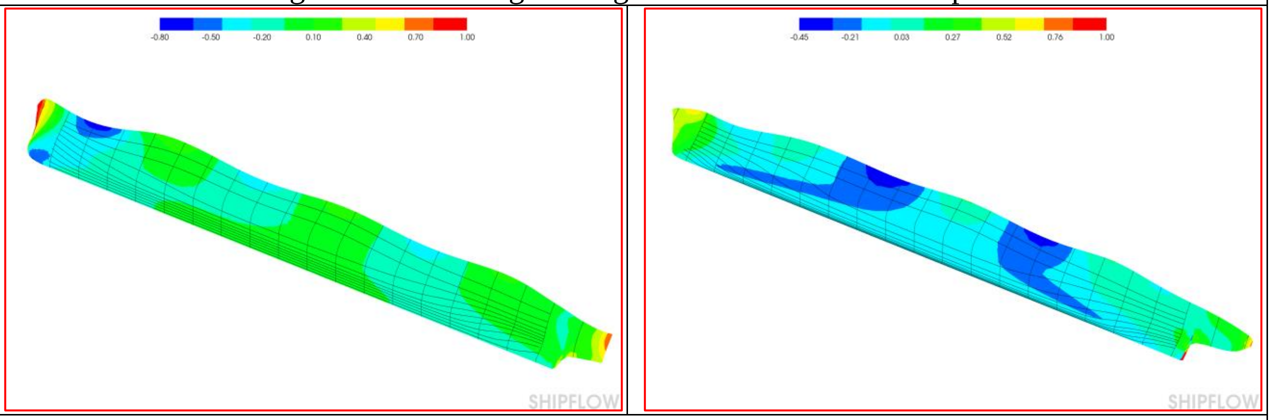

Figure 4: Pressure distribution and potential flow streamlines of vessel from Group 1

**Table 8: Comparison between parent and improved oil tanker under Group-2**

| | Parent Design | Improved Design | Change (%) |
|---|---|---|---|
| Water line length, $L_{WL}$ (meter) | 53 | 56.2 | 6.04% |
| Moulded Breadth, $B_{MLD}$ (meter) | 11 | 10.2 | -7.27% |
| $L_{WL}/B_{MLD}$ | 4.82 | 5.51 | 14.35% |
| Loaded Draft, T(meter) | 1.8 | 2 | 11.11% |
| $B_{MLD}/T$ | 6.11 | 5.1 | -16.55% |
| Block Coefficient, $C_B$ | 0.765 | 0.7 | -8.50% |
| Displacement (Tonne) | 1102 | 802 | 0.00% |
| Dead Weight (Tonne) | 530 | 530 | 0.00% |
| Speed (Knot) | 08 | 08 | 0.00% |
| Froude Number, $F_N$ | 0.18 | 0.175 | -2.89% |
| $EEDI_{BD}$ (gram/tonne.mile) | 32.79 | 28.81 | -12.12% |
| Surface Area, S ($m^2$) | 618.54 | 626.63 | 1.31% |
| Frictional Resistance Coefficient, $C_F$ | 0.00184 | 0.00193 | 4.78% |

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| | | | |
|---|---|---|---|
| Wave Resistance Coefficient, $C_W$ | 0.00164 | 0.00114 | -30.68% |
| Total Resistance Coefficient, $C_T$ | 4.04E-03 | 0.00357 | -11.67% |

As shown in table 8, 14.35% L/B ratio of vessel from Group 2 was increased by increasing 6.04% length and decreasing 7.27%% breadth. Increase in length increased the surface area by 1.31%% which has increased frictional resistance by 4.78%. However, increasing length and decrease in the block coefficient by 8.50% has made the ship slender. As a result, wave resistance has decreased by 30.68% and overall, 11.67% decrease of resistance and 12.12% energy efficiency have been achieved without sacrificing the dead weight capacity or speed.

| Parent Hull | Improved Hull |
|---|---|

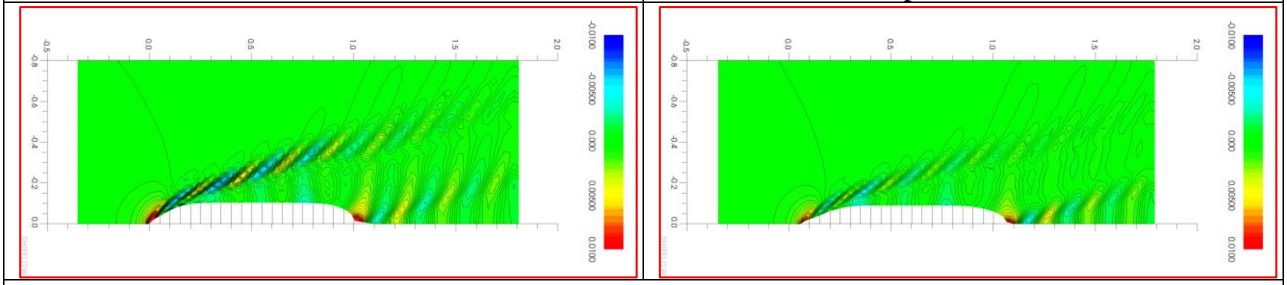

Figure 5: Free surface wave of vessel from Group 2

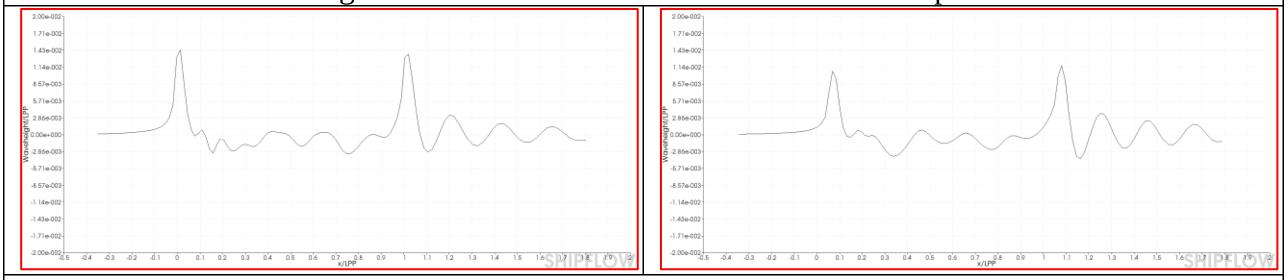

Figure 6: Wave height along hull of vessel from Group 2

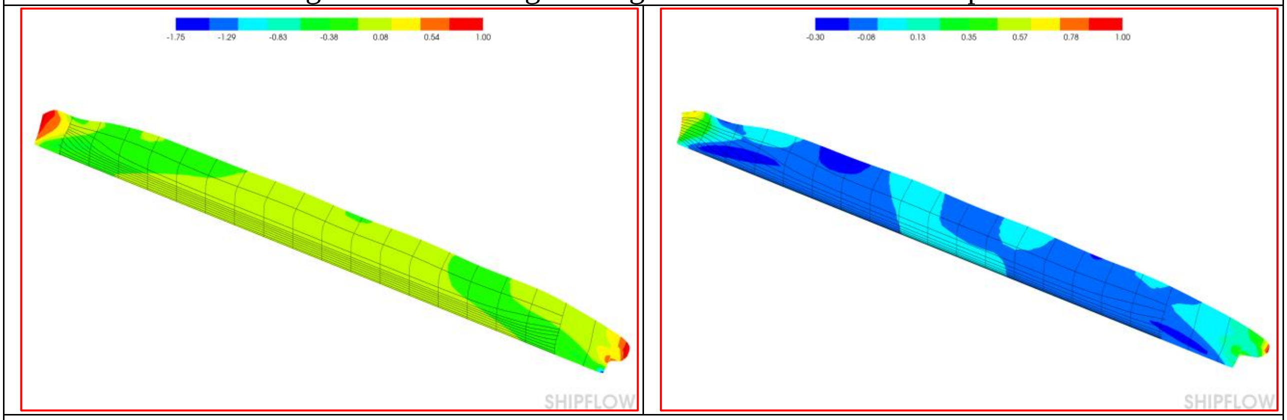

Figure 7: Pressure distribution and potential flow streamlines of vessel from Group 2

**Table 9: Comparison between parent and improved oil tanker under Group-3**

| | Parent Design | Improved Design | Change (%) |
|---|---|---|---|
| Water line length, $L_{WL}$ (meter) | 73.77 | 78 | 5.73% |
| Moulded Breadth, $B_{MLD}$ (meter) | 12.45 | 12 | -3.61% |
| $L_{WL}/B_{MLD}$ | 5.93 | 6.5 | 9.70% |
| Loaded Draft, T (meter) | 4 | 4 | 0.00% |
| $B_{MLD}/T$ | 3.11 | 3 | -3.61% |
| Block Coefficient, $C_B$ | 0.75 | 0.736 | -1.87% |
| Displacement (Tonne) | 2762 | 2762 | 0.00% |

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| | | | |
|---|---|---|---|
| Dead Weight (Tonne) | 1934 | 1934 | 0.00% |
| Speed (Knot) | 09 | 09 | 0.00% |
| Froude Number, $F_N$ | 0.172 | 0.167 | -2.75% |
| $EEDI_{BD}$ (gram/tonne.mile) | 16.19 | 14.97 | -7.54% |
| Surface Area, S ($m^2$) | 1183.09 | 1205.24 | 1.87% |
| Frictional Resistance Coefficient, $C_F$ | 0.00161 | 0.00164 | 1.83% |
| Wave Resistance Coefficient, $C_W$ | 0.00085 | 0.00081 | -5.60% |
| Total Resistance Coefficient, $C_T$ | 0.00293 | 0.00277 | -5.56% |

As shown in table 9, 9.70% L/B ratio of vessel from Group 3 was increased by increasing 5.73% length and decreasing 3.61% breadth. Increase in length increased the surface area by 1.87% which has increased frictional resistance by 1.83%. However, increasing length and decrease in the block coefficient by 1.87% has made the ship slender. As a result, wave resistance has decreased by 5.60% and overall, 5.56% decrease of resistance and 7.54% energy efficiency have been achieved without sacrificing the dead weight capacity or speed.

| Parent Hull | Improved Hull |
|---|---|

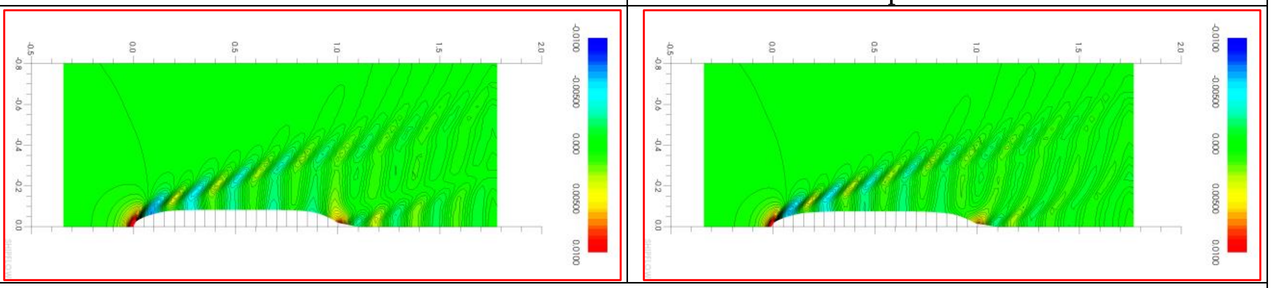

Figure 8: Free surface wave of vessel from Group 3

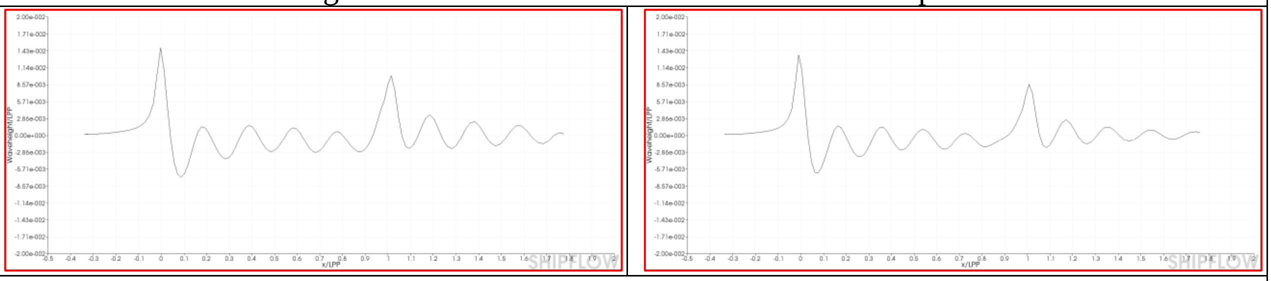

Figure 9: Wave height along hull of vessel from Group 3

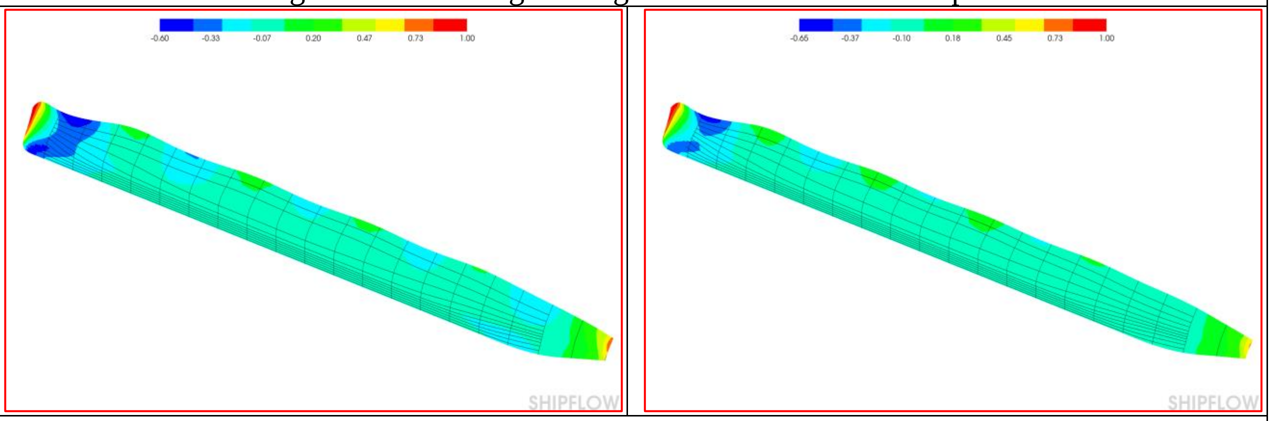

Figure 10: Pressure distribution and potential flow streamlines of vessel from Group 3

Figure 2 to 4, 5 to 7 and 8 to 10 presents the free surface wave, wave height and the pressure coefficient distribution respectively. Parent and improved hull results were presented side by side for the visual comparison. The wave pattern has been improved in the optimized hull. The distribution

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of the wave height has also improved. The pressure coefficient distribution and potential flow streamline has been improved significantly because of the hull improvement as per the suggestion from the sensitivity analysis based on EEDI. Viscous pressure resistance coefficient also improved significantly, which is presented in below table 10.

Table 10: Comparison of Viscous Pressure Resistance Coefficient for parent and improved Hull

| Group of Vessel | Viscous pressure resistance coefficient, Parent Hull | Viscous pressure resistance coefficient, Improved Hull | Improvement |
|---|---|---|---|
| Group-1 | 0.0009157 | 0.000779 | 15% |
| Group-2 | 0.0005507 | 0.0004962 | 10% |
| Group-3 | 0.0004399 | 0.0003559 | 19% |

## 6 CONCLUDING REMARKS

Though inland shipping shares a small role on the total $CO_2$ emission of global shipping, attempt to reduce $CO_2$ from current level can be very important for individual country's environmental perspective and economic point of view [10]. The prime objective of this research is to assess the possibility of $CO_2$ emission reduction from inland oil tankers of Bangladesh. The research has proved that 10-13% $CO_2$ emission reduction is possible simply by readjusting ship design parameter in light of EEDI. However, a major effort was given to develop a set of new parameters, so that EEDI formulation can be used for inland ships. The suggestion provided as a result of the sensitivity analysis have been verified by Computational Fluid Dynamics software. As a result, the suggestion of this research can be implemented practically to reduce $CO_2$ emission from current stage.

It should be understood that, for fare comparison, dead weight, speed and DWT/Displacement were kept the same for both parent and improved vessel. Only the principal particulars were adjusted based on the sensitivity analysis and EEDI value. Simple adjustment of those principal particulars has improved the hydrodynamic performance of the vessel and therefore total resistance coefficient is reduced. More reduction of EEDI value is possible with improved hull form, propeller design and other improved efficiency enhancement measures. Reduction possibility of $CO_2$ by more than 10% simply by adjusting the principal particulars of ship will not significantly increase the construction cost of the ship. In fact, the first cost could be decreased, as the main engine power requirement will decrease because of the redesign.

Another important aspect is the economic impact on individual country. It is a fact that, the total $CO_2$ emission from the inland shipping shares a very small portion of the global $CO_2$ emission. However, from the individual country's perspective, the economic impact is considerably high. Since this research has proved a $CO_2$ emission reduction possibility by at least 10% from current stage for Bangladesh, a large quantity of fuel will be saved per trip. This will have a market impact as well, because, without any exception, reduction in carrying cost will reduce the commodity price as well. Implementation of this rule will not increase construction cost of the ship, but will decrease the operational cost to large scale, apart from the direct environmental benefit

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