MOSES2019-02010

A novel approach towards more realistic energy efficiency regulations for tankers

Ivica Ančić[a*], Maja Perčić[a], Gerasimos Theotokatos[b] and Nikola Vladimir[a]

[a] University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, I. Lučića 5, 10002 Zagreb, Croatia
[b] University of Strathclyde, Department of Naval Architecture, Ocean and Marine Engineering, Maritime Safety Research Centre, Henry Dyer Building, 100 Montrose Street, Glasgow, G4 0LZ, United Kingdom
* ivica.ancic@fsb.hr

Abstract

The Energy Efficiency Design Index (EEDI) regulation introduced by the Marine Environment Protection Committee (MEPC) within International Maritime Organization (IMO) has the aim to improve new vessel designs in order to reduce the shipping sector CO_2 emissions. But the regulation, in its current form, does not effectively assess the ships energy performance. As the Attained EEDI calculation considers only a single operating point (75% main engine power, fully laden condition, calm seas, constant auxiliary engines power) and does not take into account the ship thermal power system, improvements of the ship energy efficiency cannot be assessed realistically. In this paper, a new approach is proposed to more realistically determine the energy efficiency for tankers. The proposed approach represents better the ship entire operating envelope whilst considering the major ship energy consumers. Thus, a better insight in the ship power system performance is provided allowing for the identification of operating points with low operational efficiency. If implemented for regulatory purposes, this approach could yield a higher impact on the tanker's power plant design leading to the increase of the ship energy efficiency, the reduction of the GHG emissions and the ship environmental footprint improvement.

Keywords: EEDI, tankers, energy efficiency, environmental pollution.

1 INTRODUCTION

The Energy Efficiency Design Index (EEDI), introduced by the Marine Environment Protection Committee (MEPC) within International Maritime Organization (IMO), has the aim to improve new vessel designs in order to reduce the CO_2 emissions from the shipping sector [1]. Even though the intention set by MEPC is noteworthy, there are concerns that the application of the EEDI is unlikely to further advance ship design owing to the fact the majority of the newbuildings already comply with the EEDI requirement [2]. The reason behind this is partly in the methodology used to calculate the Attained EEDI and partly in the definition of the Required EEDI. Hence, any improvements in the ship energy efficiency, such as implementing innovative energy efficient technologies cannot be assessed realistically as they can be quite effective in the considered operating point for the EEDI but their performance can greatly vary in the real operating conditions, and vice versa.

There are numerous energy efficient and carbon reduction technologies within the shipping sector available to shipowners and operators. Rehmatulla et al. [2] investigated them and showed that whilst there is a good spread of implementation across the different measures, only a selected number of them in each of the categories are implemented at a sufficient scale. The measures with high implementation have tended to be those that provide small energy efficiency gains at the ship level and the uptake of CO_2 reducing technologies (particularly alternative fuels are low despite their high potential for CO_2 emission reducing). Higher implementation rate of energy efficiency and CO_2 reducing technologies than those driven by existing regulations is required, if shipping's emissions target to be in line with other sectors in the future and follow a decarbonisation pathway. There are many recent publications dealing with different weaknesses of current regulatory framework and difficulties in its practical implementation as for instance [4], [5], [6], [7], [8]. Some indications that the adopted technical and operational measures alone would not achieve absolute emissions reduction due to projected growth of international seaborne trade are elaborated by Shi [9]. Stevens et al. [10] discussed whether the new emission legislation stimulates the implementation of sustainable energy-efficient maritime technologies or not. The conclusion of their analysis was that the EEDI regulation does not in the first place stimulate the introduction of new ship engine technologies or the use of alternative fuels, but rather makes shipping companies to order ships with a reduced design speed. However, new regulation such as Ship Energy Efficiency Management Plan (SEEMP) makes them to shift to dual fuel engine systems, rather than implement fully alternative energy systems. Such findings are relevant both to policy-makers and to shipping companies. In the context of the EEDI regulation for LNG ships, Ekanem Attah and Bucknall [11] reported that the current EEDI reference line is insufficient to stimulate improvements in the design of future LNG vessels because the current dual fuel diesel electric propulsion proposed to be installed on majority of future LNG ship orders already achieves EEDI values below the EEDI baseline. Vladimir et al. [2] studied EEDI requirements for container ships and found that majority of them satisfies the EEDI criteria without any improvements.

Lindstad and Bø [12] pointed out that it is challenging to identify EEDI-compliant solutions that reduce energy consumption and GHG emissions under realistic operational conditions by considering the existing regulatory framework. In this sense, they used an Aframax tanker class to illustrate the difference between the operational and the design conditions, simultaneously discussing costs and benefits of different options.

Tankers are a ship type group with specific characteristics. Unlike other ship types, they require significant amount of thermal power for cargo heating. Also, these ships use port infrastructure for the cargo loading, while for the cargo unloading they use pumps powered by the ship power system. Hence, both auxiliary electric and thermal ship power systems consume significant amount of fuel and thus contribute to the overall ship emissions. Tankers usually sail either fully loaded or in ballast (depending on the ship subtype and size), and also spend relatively long time in ports. Because of this, they rarely operate at the design conditions, in which the EEDI is calculated. There is a number of technologies for reducing the overall fuel oil consumption, which are unlikely to be captured by using the existing EEDI regulation. On the other hand, some options that can function only at the design condition set by the EEDI will overestimate the overall benefit on the energy efficiency and the impact to the environment.

The aim of this paper is to propose a novel approach, which could be used to determine more realistically the energy efficiency performance of tankers. Its novelty is that it is based on a holistic approach taking into account the entire ship power system, as well as real operating conditions of ships. This approach could then be implemented for regulatory purposes in order to determine and to minimize the impact of tankers on the environment, particularly considering GHG emissions.

The remaining of this paper is structured as follows. In Section 2, the currently used method is explained, its limitations are highlighted and the novel approach is described. According to these two methods the results of tankers energy efficiency performance are presented and discussed in Section 3. Based on this analysis, policy recommendations are provided in Section 4 and the final conclusions are drawn including some suggestions for further research.

2 METHODS

2.1 Currently used method

The method currently used for the evaluation of energy efficiency performance of a ship is described in detail in [13]. According to this, the *Attained EEDI* of a ship can be calculated and if its value is not greater than the *Required EEDI*, the ship is considered as energy efficient and the International Energy Efficiency Certificate can be issued to the ship. The *Required EEDI* value depends on the *EEDI reference line value* and the appropriate EEDI reduction factor *X*. The *EEDI reference line value* is obtained based on the ship type and size (capacity measured in tonnes of DWT), whilst the EEDI reduction factor is defined in a set of time intervals as provided in Table 1.

Table 1 Reduction factor values for tankers of 20,000 tonnes of DWT and above

Phase	Date of delivery	*X*
0	1 Jan 2013 – 31 Dec 2014	0
1	1 Jan 2015 – 31 Dec 2019	10
2	1 Jan 2020 – 31 Dec 2024	20
3	1 Jan 2025 and onwards	30

The ship type group that this study focuses is tankers. According to [14] this group includes oil, chemical and other liquid cargo tankers, comprising in total 21 ship subtypes. Liquefied gas carriers are not included in this group. A first limitation of the current approach is noticed; the same regulation applies to all of these ship subtypes. Even though all are classified as tankers, there are significant differences between them, as pointed out in the introduction section. The methodology used to define the EEDI reference line included ships delivered from 1 January 1999 to 1 January 2009, based on the World Register of Ships (WROS) database [15]. For these ships, their Estimated EEDI was calculated according to the following equation:

$$Estimated\ EEDI = \frac{3.1144\left(SFC_{MEi} \cdot \sum_{i=1}^{nME} P_{MEi} + SFC_{AE} \cdot P_{AE}\right)}{Capacity \cdot V_{ref}} \quad (1)$$

where P_{ME} is the main engine power, P_{AE} is the auxiliary engine(s) power, *Capacity* is expressed in tons of deadweight, and V_{ref} is the ship reference speed achievable under calm sea conditions at P_{ME} for a fully laden vessel. The constant 3.1144 represents the conversion factor of fuel to CO_2 C_F since it is assumed that all ships use HFO [14]. Although the EEDI is a measure of energy efficiency, in the currently adopted regulation it is expressed in g CO_2 per ton and nautical mile, i.e. it presents a relative CO_2 emission. This is in a tight connection with the energy efficiency, but this approach is limited only to carbon based fuels.

Further limitations of the current approach are noticed; since the EEDI formula does not include thermal power and observes only a single operating point, i.e. 75% of the main engine power and fully laden condition. The thermal power presents a significant part of the tanker power system, as concluded by Browning [16]. Browning noticed that larger tankers usually have steam driven cargo unloading pumps requiring high power, e.g. for VLCC that amounts to about 8,898 kW. This leads to higher fuel oil consumption since these boilers are not superheated and consequently higher emissions. Additionally, parameters SFC_{Mei} and SFC_{AE}, which represent specific fuel oil consumption of the main and auxiliary engine(s), are assumed to be constant and equal 190 and 215 g/kWh, respectively. Following their calculation, the *Estimated EEDI* values for the entire tanker fleet were plotted against the ship capacity. Based on this plot, using regression analysis a curve was determined as a power function by using regression analysis:

$$EEDI\ reference\ line\ value = a \cdot DWT^{c} \tag{2}$$

where the parameters *a* and *c* are obtained by the least square method. Additionally, after determining these parameters, a filtering process is applied in which all the *Estimated EEDI* values differing by more than two standard deviations from the *EEDI reference line value* are discarded. In subsequence, the regression process is repeated and the updated values of the parameters *a* and *c* are determined. Such procedure should ensure that the *EEDI reference line value* represents an average energy efficiency of a tanker for a selected capacity. In order to improve the energy efficiency of new tankers, the MEPC set the requirement that the *Attained EEDI* must not be higher than that *EEDI reference line value*, i.e. the regulation requires that the tanker must not be less energy efficient than an average tanker. The reduction factor *X* then reduces that value in time intervals. The aim is to increase energy efficiency of ships in the future with the target of obtaining 30% CO_2 reduction for ships for which the contract is placed on or after 1 January 2025.

Even though the EEDI regulation became mandatory in Phase 0 from 1 January 2013 (Table 1), it refers to ships for with their contract placed on or after that date. The EEDI regulation has been a regulatory requirement for ships delivered from 1 July 2015. Since the ships used for the EEDI reference value calculation are those delivered until 1 January 2009, there is a gap of six and a half years for which there are no records of ship energy efficiency performance.

In summary, it was shown in this section that the current EEDI regulation for application to tankers has the following limitations:

1. a single operating point is used;
2. the vessel thermal power demand is not included in the Attained EEDI formula;
3. SFC is considered to be constant;
4. the Required EEDI only depends on the ship capacity and is the same for different tankers subtypes;
5. the EEDI reference line is based on ships delivered by more than a decade ago.

2.2 Proposed method

Since the application of the existing EEDI regulation in tankers has numerous deficiencies, a new approach is proposed. This approach consists of both the Attained EEDI calculation modification (so that the energy efficiency can be correctly determined), as well as the reference EEDI calculation modification (so that a proper comparison can be made). Ancic et al. [17] proposed a similar approach for bulk carriers. However, as this approach cannot be used for tankers directly due to their specific characteristics (as indicated in the introduction section), an improved version is proposed herein for determining the energy efficiency of tankers.

The first modification proposed is to expand the EEDI to different operating points, comprising of different engine load and ship loading conditions. The difference between the EEDI and the Energy Efficiency Operational Indicator (EEOI) should be emphasized here. The EEOI is an operational measure within the SEEMP to evaluate the energy efficiency performance of a ship in operation compared to some reference value, e.g. the attained or the reference EEDI value. It has to be highlighted that the ship in its design phase usually has several design conditions (fully laden, in ballast, in port etc.). One of these conditions is 75% main engine power, full load and calm seas as adopted by the MEPC. But other design conditions, such as ballast condition and other main engine loads also need to be taken into account.

In this sense, the methodology adopted by MEPC to determine the NO_x emissions from engines [18] can be used as an example. Even though the NO_x emissions are not measured during the ship operation, the methodology prescribes different combinations of engine load and speed at which the measurements are taken. These are still the design conditions, but they reflect the operation significantly better than if only one operating point is considered.

Hence, the proposed formula to determine the *Attained EEDI* for tankers is provided by the following equation:

$$Attained\ EEDI = \sum_{x=100,75,50,25...}^{y=l,b,p...} f_{xy} \cdot Attained\ EEDI_{xy} \tag{4}$$

where the $Attained\ EEDI_{xy}$ represents total CO_2 emissions from a ship (t CO_2/h), i.e. CO_2 emissions from main engines, auxiliary engines as well as boilers at specific loads marked by *x* and *y*; *x* denotes the main engine load, whilst *y* denotes the ship load. In the current approach *x* equals 75%, and *y* equals full load, but also other engine loads (such as 100%, 50%, 25% etc.) and other ship loads (ballast, in port loading, in port unloading etc.) must be considered based on the real typical operating conditions. Since these conditions vary for different ships (and for different routes), a comprehensive analysis should be performed and a robust correlation should be established.

The *Attained EEDI* calculated in such way represents an average weighted value of the $Attained\ EEDI_{xy}$ at different combinations of ship and engine loads. Such value represents a physically justified average relative CO_2 emission from a ship which can then be used to determine its actual total CO_2 emission, as well as to compare emissions from different ships. A simplification of the proposed *Attained* $EEDI_{xy}$ is provided by the following equation:

$$Attained\ EEDI_{xy} = \\ = \sum_{i=1}^{nME} CO2_{ME(i),xy} + \sum_{i=1}^{nAE} CO2_{AE(i),xy} + \sum_{i=1}^{nB} CO2_{B(i),xy} \quad (5)$$

where the terms of the eq. (5) right-hand side represent the total CO_2 emission of the main engine(s), the auxiliary engine(s) and the boiler(s), respectively. These emissions for different operating points can be calculated based on the corresponding power, the specific fuel oil consumption and the conversion factor (as in the current approach), but for engines over 130 kW it would be more accurate to use directly data measured in the NO_x technical document.

As indicated above, apart from the *Attained EEDI* formula, a modified methodology to determine the reference EEDI is proposed. The current methodology defines the EEDI as a measure of the CO_2 emission per transport work. The transport work is defined in tons and nautical miles, which implies that it depend on the ship capacity *DWT* and speed *V*. However, the current methodology defines the reference EEDI as a function of ship capacity and does not take into account the ship speed. As a consequence, faster ships are penalized, as reporting in Lindstad et al. [19]. Therefore, it is proposed to define the reference EEDI as a function of both ship capacity and speed. The reference EEDI is then expanded from a curve into a surface, which is provided by the following equation:

$$EEDI\ reference\ surface\ value = a \cdot DWT^{c} \cdot V^{e} \quad (6)$$

where the values of the parameters *a*, *c* and *e* are obtained analogously as in the currently used method. As described in the previous subsection, the regression analysis and filtering process are both applied, but the eq. (2) with two parameters is expanded to three parameters. The data on the ships technical characteristics are also obtained from the WROS database [15] as in the currently used method.

3 RESULTS AND DISCUSSION

The EEDI reference line results for the tankers fleet with the current approach are presented by MEPC in [20]. The values of the EEDI reference line equation parameters are presented in Table 4. Since the current approach does not take into account speed as a parameter, the value of the parameter *e* is taken to be 0.

In order to estimate the values of the proposed attained EEDI according to eq. (4), the frequency of occurrence values should first have to be defined. These values should correspond to the investigated vessel real operating conditions and depend on the tanker type. In this study, these values are obtained based on the data available in the literature. There are several publications provided ship operational profiles. Banks et al. [21] analysed the operational profiles of Handysize, Aframax and Suezmax tankers, including their voyage operational time distribution (summarized in Table 2) and sailing speed distribution.

Table 2 Voyage type distribution of tankers, in percentage (taken from [19])

	Time laden	Time in ballast	Time in port
Handysize	34	11	55
Aframax	32	23	45
Suezmax	36	29	35

A more recent study by Tsitsilonis and Theotokatos [22] analysed the propulsion engine operating profiles of a very large crude carrier (VLCC), reporting the most frequent propeller curves, which shows a significant difference depending on the ship sailing mode (fully laden or ballast). In addition, they noticed that the main engine usually operates between 30 and 60% of MCR and identified the most frequent operating points of the vessel propulsion engine. Depending on the findings of these studies, an approximation in this paper is proposed to determine the typical profiles for the ship sailing modes and the main engine operating modes, which is provided in Table 3.

Table 3 Engine and ship loading frequencies of occurrences f_{xy} for Aframax tankers in operation

Main engine load	Total	Laden	Ballast	In port
	1	0.32	0.23	0.45
100%	0.05	0.03	0.02	-
75%	0.14	0.08	0.06	-
50%	0.28	0.17	0.12	-
25%	0.08	0.05	0.03	-
off	0.45	-	-	0.45

Using the values in Table 3, and the proposed approach described in Section 2.2 it is possible to define the EEDI reference surface for tankers. The values for the proposed EEDI surface equation parameters (eq. (6)), which were derived by applying the filtering process described in Section 2.1, are presented in Table 4. The coefficient of determination values (also shown in Table 4) is high for both approaches. An even more important indicator for characterising the suitability of the EEDI reference value approach is the number of vessels above and below the *EEDI reference line* or *surface*. Since, by the definition, the EEDI reference line represents the average energy efficiency for the fleet in the time period observed, the present analysis was performed for ships delivered form 1 January 2009 to 1 July 2015. These ships are not covered by the EEDI regulation. The derive results from both approaches are shown in Figure 1 and 2, respectively. It can be inferred that in the investigated time period, 3235 tankers were delivered, out of which 1004 (31%) had their Estimated EEDI above the EEDI reference line (Figure 1), whilst 1490 (46%) had their Estimated EEDI above the EEDI reference surface (Figure 2). These results are summarized in Table 5.

Table 4 Results of the EEDI reference line and the EEDI reference surface calculation based on ships delivered from 1 January 1999 and 1 January 2009

	Current approach	Suggested approach
a	1218.8	394.5
c	0.488	0.4817
e	0	1.488
R^2	0.9574	0.9675

Table 5 Results of the EEDI calculation for tankers delivered from 1 January 2009 to 15 July 2015

	Current approach	Suggested approach
Total number	3235	
Do not satisfy Phase 0	1004	1490
Do not satisfy Phase 1	1933	2421
Do not satisfy Phase 2	2766	2984
Do not satisfy Phase 3	3107	3149

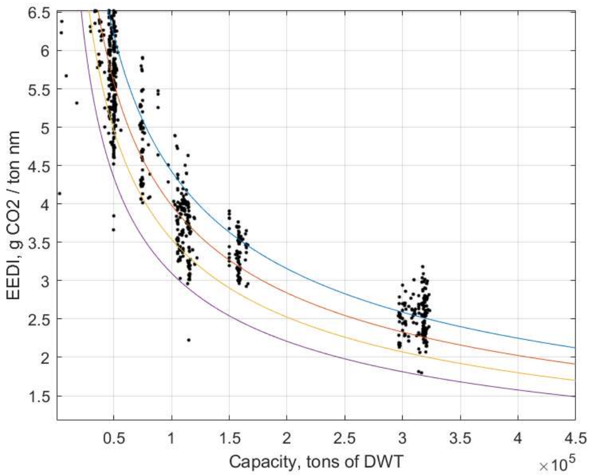

Figure 1 EEDI reference line for tankers delivered form 1 January 2009 to 1 July 2015

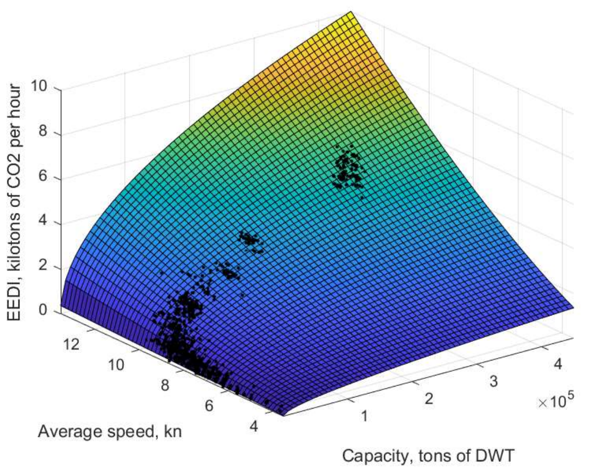

Figure 2 EEDI reference surface for tankers delivered form 1 January 2009 to 1 July 2015

The four curves plotted in Fig. 1 indicate the EEDI reference line (in blue) and the reduction curves of 10, 20 and 30%, corresponding to Phases 1, 2 and 3, respectively.

When observing the EEDI reference line and its statistical correlations, one might be tempted to argue it is a fair representation of the fleet energy efficiency due to high value of the determination factor, which equals to 0.9574 as reported in [18]. The determination factor R^2 of the proposed approach in this study equals 0.9675.

However, when analysing the energy efficiency performance of tankers in more detail (as it is also revealed from the results shown in Fig. 1), there are certain issues that need to be addressed. For instance, even though the EEDI reference line should represent average ship energy efficiency, the analysis revealed that 69% of ships delivered from 1 January 2009 to 15 July 2015 are more energy efficient "than the average" tanker of the same capacity. On the other hand, less than 4% of these ships satisfy Phase 3 requirements, and therefore it is very hard to determine whether ships delivered in that time period should be considered as energy efficient or not. In this respect, it is pointed out that the focus needs to be put on the methodology to evaluate the ships energy efficiency, which needs to clearly and reasonably account for energy efficiency improvements whilst sufficiently rewarding and acknowledging the energy efficient designs throughout the ship entire operating envelope.

4 POLICY IMPLICATIONS

As can be inferred from Table 3 results, the current methodology evaluates the ship energy efficiency performance based on operating conditions, which a tanker encounters in approximately 8% of its lifetime. Additionally, if the ship operation at different sea states is considered, this percentage would be even lower. As indicated in Section 2.2, this paper does not intend to propose the EEOI, but rather to propose the EEDI that can realistically evaluate the energy efficiency of a ship design. Otherwise, there is a risk that the newbuildings will satisfy the EEDI requirement, but the overall goal of the CO_2 emission reduction is not achieved. This can be also noticed from Table 5 data where it is clear that the majority of the newbuildings delivered from 1 January 2009 to 15 July 2015 satisfy the Phaso 0 requirement. Inclusion of these ships in the reference EEDI value calculation would definitely lower the reference EEDI, which would have then higher impact on the new vessel design. But even if the EEDI in its current form has significant impact on new tanker designs, the overall benefit for the environment can be left out.

All these issues have negative implications on policy goals, which are set for reducing the ships environmental impact. By implementing the proposed approach a more realistic insight in the energy efficiency performance of a ship can be obtained. This can then allow the regulators to amend the existing regulatory framework demanding specific improvements for the tankers power system design in order to meet the required emission targets.

5 CONCLUSION

In this paper, a novel approach to determine more realistically energy efficiency performance for tankers was proposed. The approach:

- takes into account the entire ship power system – including thermal power system;
- observes multiple engine loads;
- observes multiple ship loading conditions – fully laden, in ballast and in port;
- defines reference values based on ship capacity and average speed.

The comparison with the current approach revealed that the majority of tankers (69%) delivered from 1 January 2009 to 15 July 2015 satisfy the Phase 0 requirement. On the other hand only 4% satisfy the Phase 3 requirement without a clear indication on how to improve their power system. The proposed approach has similar results, but provides a better insight in the ship energy efficiency performance and thus can have higher impact on the tanker power system leading to the maximization of energy efficiency and the minimization of the GHG emissions. In the future research typical tankers operating profiles should be systematically analysed in order to propose the more realistic values for f_{xy}, which should be used in the *Attained EEDI* calculation.

ACKNOWLEDGMENTS

This research was supported by the Croatian Science Foundation under the project Green Modular Passenger Vessel for Mediterranean (GRiMM), (Project No. UIP-2017-05-1253). Miss Maja Perčić, Ph.D. student is supported through the "Young researchers' career development project – training of doctoral students" of the Croatian Science Foundation, funded by the European Union from the European Social Fund.

NOMENCLATURE

DWT	deadweight, t
EEDI	Energy Efficiency Design Index
EEOI	Energy Efficiency Operational Indicator
GHG	Green-House Gas
LNG	Liquefied Natural Gas
MCR	Maximum Continuous Rating, kW
MEPC	Marine Environment Protection Committee
P	Power, kW
SEEMP	Ship Energy Efficiency Management Plan
SFC	Specific Fuel Consumption, $gkW^{-1}h^{-1}$
V	ship speed, kn
VLCC	Very Large Crude Carrier
WROS	World Register Of Ships
a	parameter for the reference value, -
c	parameter for the reference value, -
e	parameter for the reference value, -
f_{xy}	weighting factor

Subscripts and superscripts

ME	main engine
AE	auxiliary engine

REFERENCES

[1] MEPC, Resolution 203(62), 2011.
[2] Vladimir N, Ančić I, Šestan A. Effect of ship size on EEDI requirements for large container ships. J Mar Sci Technol 2018;23:42-51.
[3] Rehmatulla, N., Calleya, J., Smith, T. The implementation of technical energy efficiency and CO_2 emission reduction measures in shipping, Ocean Engineering, 139; 2017: 184-197.
[4] Bøckmann, E., Steen, S. Calculation of $EEDI_{weather}$ for a general cargo vessel, Ocean Engineering 2016; 122: 68-73.
[5] Ozaki Y, Larkin J, Tikka K, Michel K. An evaluation of the Energy Efficiency Design Index (EEDI) baseline for tankers, containerships and LNG carriers, Climate Change and Sips: Increasing Energy Efficiency a SNAME & Marine Board Symposium, February 2010, USA.
[6] Johnson H, Johansson M, Andersson K. Will the ship energy efficiency management plan reduce CO2 emissions? A comparison with ISO50001 and the ISMcode. Marit. Policy Manag.: Flagship J. Int. Shipp. Port Res. 2013; 40(2), 177–190.
[7] Ancic I, Sestan A, Vladimir N. Modification of the EEDI for Ro-Ro passenger ships, World Maritime Technology Conference 2015 (SNAME Maritime Convention), Providence, Rhode Island, USA, 2015.
[8] Armstrong VN, Banks C. Integrated approach to vessel energy efficiency. Ocean Engineering 2015; 110: 39-48.
[9] Shi, Y. Reducing greenhouse gas emissions from international shipping: Is it time to consider market based measures?. Marine Policy. 2016; 64, 123-134.
[10] Stevens L, Sys C, Vanelslander T, van Hassel E. Is new emission legislation stimulating the implementation of sustainable and energy-efficient maritime technologies? Research in Transportation Business & Management 2015; 17: 14-25.
[11] Ekanem Attah E, Bucknall R. An analysis of the energy efficiency of LNG ships powering using the EEDI. Ocean Engineering 2015; 110: 62-74.
[12] Lindstad, E., Bø, T.I. Potential power setups, fuels and hull designs capable of satisfying future EEDI requirements, Transportation Research Part D: Transport and Environment 2018; 63, 276-290.
[13] MEPC, Resolution 245(66), 2014.
[14] MEPC, Resolution 215(63), 2012.
[15] IHS Fairplay, World Register of Ships Manual, 2013.
[16] Browning, L. Tanker Ship Hoteling Emissions. doi: 10.13140/RG.2.1.1943.8967, 2016.
[17] Ančić I, Theotokatos G, Vladimir N. Towards improving energy efficiency regulations of bulk carriers. Ocean engineering 2018; 148:193-201.
[18] MEPC, Resolution 177(58), 2008.
[19] Lindstad H, Asbjornslett B.E, Stromman A.H, Reductions in greenhouse gas emissions and cost by shipping at lower speeds. Energy Policy 2011; 39:3456–3464.
[20] MEPC, 62/6/4: Calculation of parameters for determination of EEDI reference values, Secretariat, 2011.
[21] Banks C, Turan O, Incecik A, Theotokatos G, Izkan S, Shewell C, Tian X. Understanding ship operating profiles with an aim to improve energy efficient ship operations. In: Low Carbon Shipping Conference, London, UK, 2013.
[22] Tsitsilonis K, Theotokatos G. A Novel Systematic Methodology for Ship Propulsion Engines Energy Management, Journal of Cleaner Production 2018, doi. 10.1016/j.jclepro.2018.08.154