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Energy Efficiency Design Index as a new criterion in ship design

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Abstract
Since 2013 Energy Efficiency Design Index (EEDI) for new ships will be enforced. Ships meeting the CO_2 emission standards will be granted energy certificate required for their exploitation. The paper presents EEDI in the current form, the certification procedure, reduced CO_2 emission planned for coming years, as well as potential for further EEDI value reduction.

Introduction

Aiming at the so called greenhouse gas reduction (including CO_2) has resulted in the introduction of new criteria and standards, in combustion engine design or entire means of transport. IMO has drawn up Energy Efficiency Design Index (EEDI) for newly built and designed ships, mandatory since 2013, which is defined as follows:

$$\mathrm{EEDI} = \frac{\mathrm{CO_2\ emission}}{\mathrm{transport\ work}} \tag{1}$$

and expressed in CO_2 grammes/1 tonne – mile of transported cargo.

Introduction of such criterion is to enforce such ship design and exploitation (together with its propulsion) as to decrease CO_2 emission (CO_2 emission will be gradually reduced in subsequent years).

Although, the main aim of the EEDI is CO_2 reduction, still the very structure of this index allows it to be used as yet another design criterion, as well as some kind of transport efficiency measure. Proper application of EEDI in ship design can therefore reduce CO_2 emission on the one hand, and lead to optimal choice of technical and service parameters on the other, which in turn maximise economic performance for a shipowner.

Energy Efficiency Design Index

Research into EEDI has been carried out for years now. As a basis laid the assumption that sea transport of cargo is also associated with CO_2 emission, which has been defined as [1]:

$$\mathrm{Attained\ design\ CO_2\ index} = \frac{C_F \cdot \mathrm{SFC} \cdot \mathrm{P}}{\mathrm{Capacity} \cdot V_{\mathrm{ref}}} \tag{2}$$

where:
- C_F – conversion factor between fuel consumption and CO_2 emission;
- SFC – specific fuel consumption;
- P – 75% of the rated installed power (MCR);
- V_{ref} – the ship speed at specified at calm sea (no wind, no waves).

The formula (2) was initially a complex one with additional coefficients. There have been over a dozen of corrections and amendments in total, proposed mainly by Denmark, Japan, and the USA. The current version, subject to further research and analysis, recommended for ship design is presented below [2]:

$$\frac{\prod_{j=1}^{M} f_j \left(\sum_{i=1}^{n\mathrm{ME}} P_{\mathrm{ME}(i)} C_{\mathrm{FME}(i)} \mathrm{SFC}_{\mathrm{ME}(i)} \right) + (P_{\mathrm{AE}} C_{\mathrm{FAE}} \mathrm{SFC}_{\mathrm{AE}})}{f_i \cdot \mathrm{Capacity} \cdot V_{\mathrm{ref}} \cdot f_w} +$$
$$+ \frac{\left(\prod_{j=1}^{M} f_j \left(\sum_{i=1}^{n\mathrm{PTI}} P_{\mathrm{PTI}(i)} - \sum_{i=1}^{n\mathrm{eff}} f_{\mathrm{eff}(i)} P_{\mathrm{AEeff}(i)} \right) C_{\mathrm{FAE}} \mathrm{SFC}_{\mathrm{AE}} \right)}{f_i \cdot \mathrm{Capacity} \cdot V_{\mathrm{ref}} \cdot f_w} +$$
$$- \frac{\left(\sum_{i=1}^{n\mathrm{eff}} f_{\mathrm{eff}(i)} P_{\mathrm{eff}(i)} C_{\mathrm{FME}} \mathrm{SFC}_{\mathrm{ME}} \right)}{f_i \cdot \mathrm{Capacity} \cdot V_{\mathrm{ref}} \cdot f_w} \tag{3}$$

where:

$C_{FME(i)}$ – a non-dimensional conversion factor between fuel consumption (in grams) and CO_2 emission (also in grams) on the basis of carbon content, table 1;

$SFC_{ME(i)}$ – specific fuel consumption (main engine);

$P_{ME(i)}$ – 75% ships' total installed main power (MCR);

C_{FAE} – a non-dimensional conversion factor (like $C_{FME(i)}$) for auxiliary engines;

SFC_{AE} – specific fuel consumption (auxiliary engines);

P_{AE} – power of auxiliary engines, IMO MEPC define it according to MCR for ships power below and above 10,000 kW;

$P_{PTI(i)}$ – 75% shaft motor power;

$P_{AEeff(i)}$ – auxiliary power reduction (electric power generated by waste heat recovery with $P_{ME(i)}$;

$f_{eff(i)}$ – availability factor of innovative energy efficiency technology (if used);

$P_{eff(i)}$ – output of innovative mechanical energy efficient technology;

V_{ref} – the ship speed, measured in nautical miles per hour (knot), on deepwater in the condition of maximum allowed summer load draught as provided in confirmed stability information;

Capacity – deadweight for all types of carriers and gross tonnage for passanger ships;

f_i – the capacity factor for any technical / regulatory limitation on capacity;

f_w – a non-dimensional coefficient indicating the decrease of speed in representative sea conditions of wave height, wave frequency and wind speed;

f_j – a correction factor to account for ship specific design elements.

The EEDI formula has been drawn up mainly for conventional propulsion systems (combustion engine) and does not have to be used in other propulsion systems such as: Diesel-electric, turbine, or hybrid propulsion types.

The EDDI formula is quite a complex one, where two basic groups of parameters can be distinguished:

- the first group, pertaining to the marine power plant, that is main and auxillary engine(s) power, specific fuel consumption, conversion factors between fuel consumption and CO_2 emission, power of waste heat generators, as well as parameters defining the application and use of innovative technology – given in the formula numerator (3);

Table 1. Non-dimensional factor C_F for different type of fuel [2]

Type of fuel	Reference	Carbon content	C_F (t-CO_2/ t-Fuel)
1.Diesel / Gas Oil	ISO 8217 Grades DMX through DMC	0.875	3.206000
2.Light Fuel Oil (LFO)	ISO 8217 Grades RMA through RMD	0.86	3.151040
3.Heavy Fuel Oil (HFO)	ISO 8217 Grades RME through RMK	0.85	3.114400
4.Liquified Petroleum Gas (LPG)	Propane Butane	0.819 0.827	3.000000 3.030000
5.Liquified Natural Gas (LPG)		0.75	2.750000

- the first group, pertaining to ship exploitation, that is, the capacity, the ship speed on calm sea, the decrease of a ship speed in real-life weather conditions, which can be found in the formula denominator, as well as a nominator parameter defining type and specific work conditions e.g. sailing through ice.

Currently binding EEDI version is by no means final, although it will be mandatory since 2013. It has been widely discussed, with numerous changes proposed e.g. on values or the calculation methods of some parameters (power, speed, capacity) or their coefficients (e.g. decrease in ship speed on rough sea).

Reference line

In order to establish the expected CO_2 emission, a reference line has been drawn up for various types of ships of different sizes. It will be enforced since 2013. EEDI calculation will be performed for each newly built ship and compared against the appropriate reference line (for the ship type and size). If the EEDI value will be equal or smaller than that on the reference line, the ship will be granted International Energy Certificate and fit for exploitation. Examples of reference lines in 2013 are given in figures 1–3.

Methodology for defining the reference line was first proposed by Denmark. In order to determine the reference line (base line) Lloyd's Register Fairplay (LRFP) data on existing, already built ships was used. Such data is incomplete, therefore some simplifications had to be made, or some missing data completed using similar ships with regression relation. For all the ships used, a constant specific fuel consumption (SPF) was assumed, independently from the actual engine of a ship. The calculations do not include potential shaft generators, although they might have been present on some of the ships. Therefore, the EDDI values as seen on figures 1–3 are above the reference line, which is not necessarily true. Thus, further research has been undergoing in order to adjust the reference line as needed, especially for some types of large capacity ships. In order to facilitate EEDI estimation for a newly built ship and establish whether it

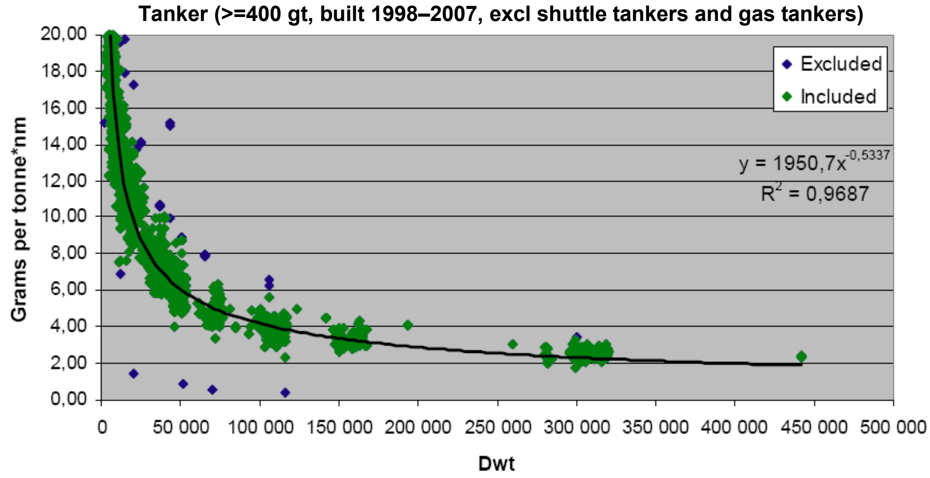

Fig. 1. Reference line for tanker ships [3]

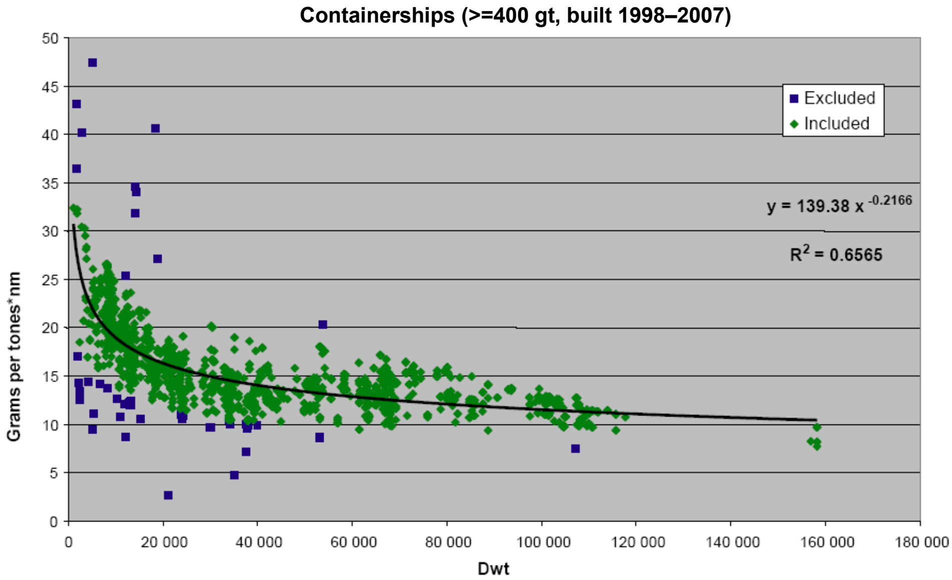

Fig. 2. Reference line for containerships [3]

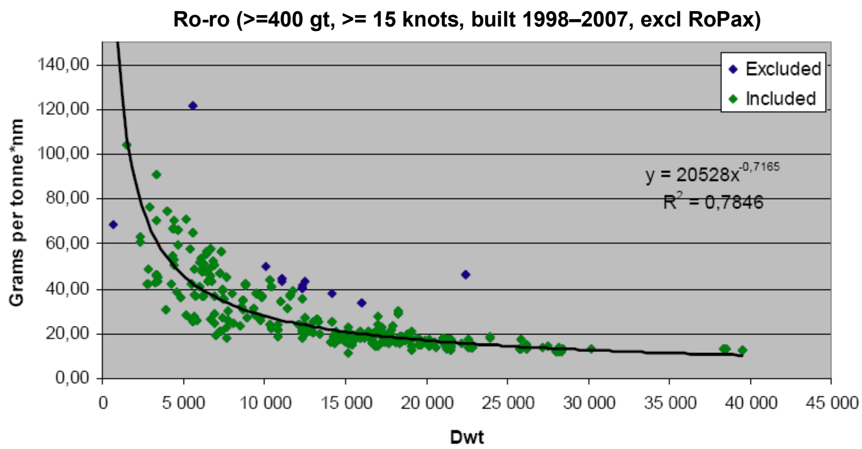

Fig. 3. Reference line for Ro-ro cargo ships [3]

meets the CO_2 emission criteria, the reference line has been approximated as follows [4]:

$$L_{\text{ref}} = ab^{(-c)} \tag{4}$$

where: a, b, c are parameters, whose values for each ship type are presented in the table 2.

Table 2. Parameters for determination of reference values for the different ship types [4]

Ship type defined in regulation 2	a	b	c
2.25 Bulk carrier	961.79	DWT of the ship	0.477
2.26 Gas carrier	1120.00	DWT of the ship	0.456
2.27 Tanker	1218.80	DWT of the ship	0.488
2.28 Container ship	174.22	DWT of the ship	0.201
2.29 General cargo ship	107.48	DWT of the ship	0.216
2.30 Refrigerated cargo carrier	227.01	DWT of the ship	0.244
2.31 Combination carrier	1219.00	DWT of the ship	0.488

Since further reduction in CO_2 emission is planned for subsequent years, then the reference line will be changing accordingly. Prognostic values of CO_2 (expressed as a percent in relation to the basal values of reference line in 2013) are given in table 3.

International Energy Certificate of a ship

EEDI value calculation and International Energy Certificate for a new ship will be issued by the state Marine Administration on the basis of approved ship design documentation. It means that the subsequent ship exploitation together with changeable sailing conditions (shipping routes, weather) will have no influence on the EEDI value.

The EEDI certificate is therefore valid throughout the life of the ship [4], unless the ship undergoes a major conversion, so as it is regarded as a new ship. The certificate loses its validity when the ship is withdrawn from the service or transferred to the flag of another state (sold, hired). It is possible, however, that the marine administration of both contracting states, reach the agreement and transmit the certificate together with the copies of the relevant survey reports to the new ship's operator within three-months period. Subject to specified conditions the certificate is deemed valid.

In some documents and publications it is emphasized that in order to reduce CO_2 emission, the shipping routes must be optimalised, the service speed of the ship decreased or higher quality fuel used. According to the currently binding criteria, such activities – although environmentally friendly – will not affect the already calculated EEDI value, and hence be decisive in meeting the required standards for the international energy certificate.

EEDI guidelines in ship design

Reference lines shown on figures 1–3 are the product of statistical analysis of EEDI values for various ship sizes (capacity) of the existing vessels of the same time, built in different years.

Although, the reference lines result from approximate EEDI calculation values, still, however even with the exact EEDI calculation value, there will be some ships, whose EEDI will be above the reference line. As the table 3 shows, the reduction factor of CO_2 emission from newly built ships with combustion engines will be steadily increasing. Therefore, even at present the significant potential

Table 3. Reduction factors (in percentage) for the EEDI relative to the EEDI Reference line [4]

Ship Type	Size	Phase 0 1 Jan 2013 – 31 Dec 2014	Phase 1 1 Jan 2015 – 31 Dec 2019	Phase 2 1 Jan 2020 – 31 Dec 2024	Phase 3 1 Jan 2025 – and onwards
Bulk carrier	20,000 DWT and above	0	10	20	30
	10,000 – 20,000 DWT	n/a	0–10*	0–20*	0–30*
Gas carrier	10,000 DWT and above	0	10	20	30
	2,000 – 10,000 DWT	n/a	0–10*	0–20*	0–30*
Tanker	20,000 DWT and above	0	10	20	30
	4,000 – 20,000 DWT	n/a	0–10*	0–20*	0–30*
Container ship	15,000 DWT and above	0	10	20	30
	10,000 – 15,000 DWT	n/a	0–10*	0–20*	0–30*
General cargo ship	15,000 DWT and above	0	10	20	30
	3,000 – 15,000 DWT	n/a	0–10*	0–20*	0–30*
Refrigerated cargo carrier	5,000 DWT and above	0	10	20	30
	3,000 – 5,000 DWT	n/a	0–10*	0–20*	0–30*
Combination carrier	20,000 DWT and above	0	10	20	30
	4,000 – 20,000 DWT	n/a	0–10*	0–20*	0–30*

for decreasing EEDI values (and at the same time improving the ship energy efficiency) is indicated as follows:

- improved hull design aiming at higher propulsion efficiency;
- more efficient propulsion engine – lower specific fuel consumption;
- higher fuel quality;
- development of new technologies, better waste heat recovery system;
- larger ship construction (bigger capacity);
- decreasing the ship's speed;
- optimalisation of the shipping route.

While some of the above suggestions do not play any major role now, since e.g. EEDI value together with certificate is determined for a newly built ship and its future service together with shipping route optimalisation is not taken into account; there are still other – pertaining to the propulsion engine, new technologies or fuel quality, which can be worked upon bearing in mind that our experience in these fields so far suggests that further improvements will not be revolutionary.

Low-speed engines, in turn, use the lowest quality fuel, which makes them economical to use. Building larger ships, suggested above, is not always profitable for the ship operator and the distribution of the ports large enough for them must be taken into account as well. Decrease in service speed of a ship is possible, but necessarily within safety limit. Even now, the IMO has published a guideline, suggesting that decrease in service speed in order to lower the EEDI value of a ship must not impede ship safety that is manoeuvrability of the ship under adverse conditions or safe sailing against the opposite or oblique wave.

The remaining factor – i.e. optimalisation of the hull design, in order to achieve a better propulsion efficiency (hull-propeller-plane ruder located behind the propeller) can be carried out in two stages:

- global optimalisation of main design parameters aiming at the maximum reduction of ship's resistance (and at the same time propulsion efficiency) for a given ship capacity and service speed, taking into consideration all other requirements e.g. technical;
- local optimalisation – changes in ship hull geometry in the stern section in order to achieve higher propulsion efficiency of the system: hull-propeller-plane rudder located behind the propeller.

The above considerations for improvement in hull design seem very attractive, however, they could possibly be used for an unfounded suggestion, that the EEDI value of a new ship is lower than the actual. What is more, as already stated in some projects, it is possible to estimate the EEDI value in a dishonest way taking advantage of possible lack of precision in regulations.

The suggestion of EEDI application as a new criterion in global optimalisation of transport ship design has been presented in [5], while the detailed account of numerical analyses (computational fluid dynamics – CFD) used in local optimalisation of hull-propeller-plane rudder design can be found in [6, 7].

Conclusions

EEDI although mandatory since 2013 seems to need some further discussion in order to ensure that the International Energy Certificate is awarded without impeding the ship safety and in full transparency as to avoid dishonest practices (taking advantage of some lack of precision).

Meeting the standards for CO_2 emission required for the international energy certificate for the ships built and designed at present is by no means difficult.

Meeting such standards (CO_2 emission) in the coming years will require more effort resulting in an improved ship design (resistance-propulsion relationship, propulsion system, overall ship energy consumption).

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