About the indicator of energy efficiency of ships

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Abstract. An analysis of parameters proposed by the International Maritime Organization for assessing the energy efficiency of ships is presented in the article. The physical assumptions underlying the methods for determining these parameters are considered: Energy Efficiency Design Index and Energy Efficiency Operational Indicator of ships. It is shown that the IMO parameters proposed cannot be used to assess the energy efficiency of ships and are meters of CO2 emissions from ship engines or, at best, indicators of fuel use by vessels in operation.

1. Introduction
IMO marine environment protection Committee (IMO MEPC), at its 59th session, held from 13 to 17 July 2009, recognized the need to develop a constructive energy efficiency index for new vessels in order to encourage innovation and technological advances in all elements of the vessel and to assess the energy efficiency of the vessel (energy efficiency) at its design stage [1].

In the original IMO document MEPC.1 / Circ. 681 from August 17, 2009 the indicator of projected energy efficiency designation – EEDI was introduced. IMO MEPC, in an effort to enable the use of the formula for determining the EEDI for all categories of vessels, including technical parameters in the EEDI formula, agreed on the application of the interim guidance for the calculation of the EEDI.

2. Method of calculation of constructive energy efficiency index
IMO MEPC recognized the need of further development and improvement the calculation method of the EEDI and invited interested organizations to use the interim manual to test its basic provisions on a voluntary basis for both vessels with traditional propulsion systems (main drive) and vessels with non-conventional propulsion systems (diesel-electric, turbine and hybrid propulsion systems).

After several years of “trial operation” of the interim guidance of the IMO MEPC by resolution MERC.2003(62) adopted amendments to Annex VI to the International Convention for the prevention of pollution from ships1973, as amended by the 1978 Protocol thereto (MARPOL 73/78), which entered into force on 1 January 2013 [2]. In particular, Annex VI to MARPOL 73/78 introduces Chapter IV «energy efficiency Regulations for ships» (rules 19 – 22) and Appendix VIII «Form of the international energy efficiency certificate» (Certificate IEE).

Leaving the description of the EEDI calculation method required by MARPOL and comments [3-5] outside the scope of the article, let us turn to the initial provisions on the basis of which the IMO MEPC agreed on the method of calculation of the EEDI in 2009. The method of determining the EEDI based on the scheme of the power plant of the vessel, is shown in figure 1.
The problem of the need for a powerful electric energy storage (battery), we, as well as the IMO MEPC, leave beyond the scope of the article. Note here that the presence of a hybrid motor in the circuit slightly improves the idea of the usefulness of the EEDI. In a generalized form, the formula for determining the EEDI can be represented as follows:

$$ EEDI = \frac{Design\ value\ of\ fuel\ consumption\ by\ all\ ship\ users \times f_{CO_2}}{Useful\ capacity\ of\ the\ vessel\ provided\ by\ the\ project}, $$

where $f_{CO_2}$ — the factor of reduction of fuel consumption emissions CO₂.

When determining the design value of the fuel consumption, it is taken into account that the main engines operate at 75% of the installed power value minus the power of the shaft-driven generator; the power of auxiliary engines is assigned to the function of the installed power of the main engines (5% for ships with a power plant capacity of less than 10 000 kW), fuel economy is due to the application of innovations that increase the mechanical efficiency of engines, and innovations in the use of electric energy. The latest fuel economy articles, however, are described very vaguely, which raises doubts about the possibility of taking into account this fuel economy in practice.

The useful capacity of a vessel is determined by multiplying the vessel's capacity (deadweight, gross tonnage, 65% of deadweight for different types of vessels) by the vessel's speed in nautical miles, with the use of coefficients taking into account the possible speed reduction due to weather conditions, as well as the capacity reduction due to technical and organizational constraints.
The factor of bringing fuel consumption to CO$_2$ emissions is the one that varies for different fuels and depends on the carbon content of the fuel. With the help of this coefficient, the assumption is made that the amount of fuel burned is linearly related to the amount of CO$_2$ emitted into the atmosphere, that is, the quality of fuel combustion in the engine cylinders is not taken into account (it is not taken into account that not all the carbon of liquid or gaseous fuel is completely oxidized by oxygen).

Extremely doubtful for the practical implementation is the method of determining the fuel consumption by subtracting from the fuel consumption spent by auxiliary engines for generating electric energy for the engine, giving its power to the propeller shaft ("hybrid" engine), fuel consumption reduction by auxiliary engines, due to the use of innovative technologies. The last term of the EEDI formula numerator that characterizes the fuel economy of the main engines, due to innovations in the field of converting the heat of the burned fuel into mechanical work (in other words, due to the increase in efficiency of the main engines), also seems to be of little use for practical calculations.

The analysis of the formula for determining the EEDI shows that EEDI in fact does not characterize the energy efficiency, as, in fact, does not characterize the environmental efficiency of ships for the following reasons.

First. EEDI is a dimensional measure that decreases with decreasing fuel consumption (CO$_2$ emissions). This circumstance requires regulation of the EEDI, which differs from the regulation of this value for ships. To develop a method of rationing it is necessary to carry out a separate research work. However, the implementation of this work, which will determine the limit of permissible values of EEDI, below which the field of acceptable values of EEDI will be located, will not facilitate the task of determining the energy efficiency in the literal sense of the word.

Second. The concept of "efficiency" has little application to the EEDI. Efficiency at all times was called the ratio of the beneficial effect to the cost of obtaining this effect. Most often, efficiency is a dimensionless quantity that tends ideally to one (100 %). Nothing of the kind is seen here.

It should be pointed out, however, that the EEDI takes into account correctly the relationship between fuel consumption and CO$_2$ emissions: the lower the fuel consumption of the vessel, the more economical the vessel is and its environmental performance – CO$_2$ emissions – is more favorable. Apparently, this is the only reason why the developers of EEDI called this parameter the energy efficiency index (in terms of fuel consumption related to the work performed by the vessel). Otherwise, EEDI allows evaluating a ship that performs the same job compared to another ship as more efficient if the job is done with less fuel and therefore less CO$_2$ emissions.

Summarizing the above-mentioned, it can be noted that EEDI is more properly to be called the index of greenhouse gas emissions or the CO$_2$ efficiency index of the fuel consumption of the ship, or the index of the greenhouse gas CO$_2$, while simultaneously characterizing the fuel efficiency to convert its energy into transport work, but not the energy performance index [6]. In fact, the IMO MEPC, which agreed on the application of the interim guidance on the method of calculating the constructive energy efficiency index for new vessels at its 59th session, states explicitly: «the EEDI applied to new vessels is a CO$_2$ emission meter».

All the complications of the formula for determining the EEDI, for example, taking into account the work of the shafts generator, «hybrid engine», innovative technologies, the real speed of the vessel, etc., are made at a very inaccurate level. To us, these complications seem to be unsuccessful attempts to describe, at the design stage, as close as possible to reality, the expected fuel consumption of the vessel, taking into account the equipment installed, and the transport work performed by the vessel per unit of time.

With regard to the latter parameter, it can be stated that the fuel consumption of the vessel related to the operational work (t.km or passenger.km) during the planned economy was one of the main indicators characterizing the energy saving in the river fleet vessels.

Third. In the formula for the definition of EEDI, there is no fuel consumption by a stand-alone boiler, which is known to be reduced if the heat of the exhaust gases, engine cooling water, lubricating oil and pressurized air are utilized, thereby contributing to the truly energy efficiency of the vessel.
Accounting for heat recovery or the lack thereof using the coefficient $f_{	ext{eff}(i)}$ (coefficient taking into account the application of each innovative technology that increases energy efficiency) is insufficient (if there is a utilization, then $f_{	ext{eff}(i)} = 1$, if not, then there are no recommendations). In addition, the coefficient under consideration according to the formula for determining the EEDI increases or decreases the $\text{PAE}_{\text{eff}(i)}$ parameter characterizing the reduction in the power of auxiliary engines due to the use of innovative technologies in the field of electric energy, which in itself is not clear.

The disadvantage of the technique and scheme shown in figure 1 is the lack of consideration of the possible use of wind energy for additional generation of electric energy when moving the vessel.

Thus, the EEDI figure, in relation to inland navigation vessels can scarcely be calculated by the IMO method. We have calculated the values of this parameter for the dry cargo ship of the project № 507B and the passenger ship of the project № 302.

According to the results of the calculations it turns out that the passenger ship due to the greater gross capacity has a lower value of EEDI (10.13 g CO$_2$ / (t .km) than the dry cargo ship (13.50 g CO$_2$ / (t.km)), but greater energy efficiency, although the CO$_2$ emissions of the ship of the project № 302 is 2.61 times more than the CO$_2$ emissions of the cargo ship. It was not taken into account that a very efficient utilization boiler is installed in the ships of the project № which significantly reduces the fuel consumption of the autonomous boiler and thus contributes to energy saving.

The results of the calculations confirm the preliminary conclusion that the EEDI is not suitable for assessing the energy and environmental efficiency of inland navigation vessels.

3. Using the operational energy efficiency indicator

The operational energy efficiency indicator of the vessel was proposed by the IMO MEPC at the 59th session to be used on a voluntary basis. This parameter is denoted by EEOI and is defined by the following equation:

$$EEOI = \frac{M_{\text{CO}_2}}{\text{transportation work}},$$

where $M_{\text{CO}_2}$ – weight of carbon dioxide emitted into the atmosphere as a result of fuel combustion on the vessel, tons:

$$M_{\text{CO}_2} = \sum_j FC_j \cdot C_{F_j};$$

where $FC_j$ – fuel consumption of the vessel for the voyage or the period of operation, for example, during the day’s work of the main and auxiliary engines, boiler and incinerator, tons; $C_{F_j}$ – dimensionless factor of fuel consumption reduction to CO$_2$ emission, depending on the carbon content in the fuel.

Transport work is calculated using the equation:

$$\text{transportation work} = \sum_j \left( m_{\text{cargo}} D_j \cdot D_j \right),$$

where $m_{\text{cargo}}$ – cargo carried or work performed (number of containers or passengers), or gross tonnage for passenger vessels; $D$ – distance corresponding to the work performed for the carriage of cargo or passengers, nautical miles.

Thus, the dimension of EEOI can be $\frac{T_{\text{CO}_2}}{\text{number of passengers} \cdot \text{nautical mile}}$, $\frac{T_{\text{CO}_2}}{\text{number of containers} \cdot \text{nautical mile}}$, and so on.

We will evaluate the possibility of using EEOI on inland navigation vessels. In the recent past, the river fleet as one of the main indicators of energy saving of the ship, or rather the use of fuel, was the indicator $T_{\text{FUEL}} / (\text{tons} \cdot \text{km})$ or $T_{\text{FUEL}} / (\text{pass} \cdot \text{km})$, where $T_{\text{FUEL}}$ – fuel consumption for the reported period, tons.

This utilization of the fuel has essentially no difference from the EEOI, if not to take into account the relationship of the fossil fuel consumption with CO$_2$ emissions and to replace the nautical mile,
taken at the river gauge of speed «kilometers per hour». Therefore, EEOI can be used to estimate CO₂ greenhouse gas emissions with little or no adaptation to the operating conditions of ships on inland waterways. However, this option should be called the CO₂ emissions related to fuel used by the vessel, and to use it for evaluating by the Supervisory authorities environment pollution by ships greenhouse gas emissions and, simultaneously, to assess the efficiency of the transport operation of the fleet.

4. Conclusion
The use of EEDI and EEOI parameters does not eliminate the problem of normalization of these parameters, which requires a separate study.

References
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