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TECHNICAL AND OPERATIONAL MEASURES TO REDUCE GREENHOUSE GAS EMISSIONS AND IMPROVE THE ENVIRONMENTAL AND ENERGY EFFICIENCY OF SHIPS

Summary. Every year, the dynamics of implementation of projects aimed at improving the efficiency of energy use is gradually increasing at different levels and in different industries. It has spread in the areas of design, modernization and reconstruction of energy-efficient buildings and structures, design and construction of elements of industrial infrastructure, and technological production processes. Introduction of such projects is a priority for enterprises and companies of various types of economic activity. Thus, the leading industries develop strategies to improve environmental safety and energy efficiency - shipping is no exception, where the process of improving energy efficiency is carried out through various

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mechanisms, ultimately leading to a reduction in emissions of pollutants, but having a negative impact on the performance of the commercial operation of the ship. Problems of ensuring energy efficiency along with increasing requirements for environmental safety of transport and strengthening the responsibility of shipowners become the focus of research of modern theory and practice of operation of means of maritime transport. The issues of improvement of universal principles of energy efficiency within individual shipping companies and development of tools for economic analysis of energy efficiency of own fleet, search for new ways of forming professional competencies of ship crew members in the field of energy efficiency continue to be topical as well.

Keywords: ships energy efficiency, design index, management plan

1. INTRODUCTION

Analogous to SOLAS (International Convention for the Safety of Life at Sea), which regulates shipping according to the minimum standards to protect life at sea, MARPOL (The International Convention for the Prevention of Pollution from Ships) is another important convention that protects the marine environment from pollution from ships. MARPOL and SOLAS are considered two effective instruments of the IMO (International Maritime Organization) in the field of safety and environmental protection. Continuous technical development and innovation are the key areas in the process of improving the energy efficiency of ships. For some time, control over the efficient use of energy resources by ships has been voluntarily, and shipowners were expected to be aware of their responsibility for the energy efficiency of their fleet. However, due to growing concerns about increasing greenhouse gas emissions and fuel consumption, several steps have been taken by the IMO's maritime industry regulator MEPC (Marine Environment Protection Committee) to reduce greenhouse gas emissions from ships, namely the adoption of MARPOL Annex VI, Chapter 4, Ship Energy Efficiency Regulations. The main objective has been to introduce two mandatory mechanisms - the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP).

The problems of ensuring energy efficiency along with the improvement of environmental safety of ships have always been given close attention, both by leading scientists in the field of water transport and international organizations and institutions. Thus, features of the use of alternative types of fuel are considered in works [1-3]. Means and methods of ship energy efficiency management are investigated in [4-6]. The disclosure of the basic principles and measures on increase energy efficiency on ships is offered in [7, 8]. Guidelines for considering innovative energy efficiency technologies for calculation and verification of achieved performance for ships in adverse weather conditions and regulatory requirements from controlling organizations are presented in [9-11]. In [12-14, 18], the operational energy efficiency performance of a ship based on the influence of the navigational environment and the optimization of ship time in port are analyzed. In [15-17], works are devoted to the study of the ship's performance under various operating conditions. Chemical tracers of particulate emissions from commercial shipping and new trends in environmental friendliness of ship power plants are reviewed in [21, 24]. Papers and regulations on the implementation of the Energy Efficiency Design Index [20, 23]. However, the search for ways to reduce emissions of harmful substances from ships and the issues of improving the energy efficiency of vessels through the implementation of various operational methods, are characterized by a high degree of relevance.

2. MATERIALS AND METHODS

Today, the world community devotes special attention to the problem of preventing pollution of atmospheric air. In 1997, the Kyoto Protocol was adopted - an additional agreement to the framework, UN Convention on Climate Change. The protocol establishes a procedure for reducing greenhouse gas emissions into the atmosphere, mainly CO_2. The governments of almost all countries of the world are required to limit some human activities, such as the burning of fossil fuels, which leads to the release of gases that affect the climate into the atmosphere. The Paris Climate Conference (October-March 2015) strengthened the standards for releases of toxic substances into the atmosphere.

Maritime transport plays an important role in the pollution of the environment. Currently, the global call for environmental protection in the maritime transport community has been added to these circumstances concerning the pollution of water resources and the atmosphere. The International Maritime Organization (IMO) has confirmed this environmental concern by setting more demanding requirements. To prevent air pollution from ships, MARPOL (1997) Addendum VI prohibits disposal of ozone-depleting substances following the Montreal Protocol; it also regulates the disposal of exhaust gases: NOx - 6-10 % reduction as compared to uncontrolled engines, SOx - allowed limit in standard areas - 4.5%, and in emission control areas (SECA) - 1.5%.

The new edition of Supplement VI took shape beginning at the 53rd and ending at the 59th sessions of the IMO Marine Environment Protection Committee (MEPC), which came into effect on 1 June 2010. According to the new edition, the amount of nitrogen (NOx) is divided into three levels: Level I represents the interval of NOx at this time, which was adopted in the industry and transport (this includes engines installed from 1990 to 1999 with cylinder capacity up to 5000 kW and a cubic capacity of 90 liters); Level II - reduced by 15.5 - 21.8% in comparison with Level I of the standard on the amount of NOx for new engines installed on vessels built before June 1, 2010, or later; Level III - reduced by 80% of Level II standard on the concentration of NOx for new engines installed on vessels built before June 1, 2016, or later.

Regarding CO_X and particulate matter content of the exhaust gases specified in Appendix VI, it should be noted that specific limits for particulate matter content are not specified, as they depend on sulfur content (S). On a global scale, the standard of limiting particulate matter content is 4.5% until June 1, 2012, 3.5% after that date, and 0.05% from June 1, 2020.

In the SECA areas (Figure 1) (Baltic and Black Sea (EECA), North America (NAECA), etc.), the standard for the amount of Sulfur before June 1, 2015, is 1.0%, and 0.1% after that date.

To meet the established standards, it is planned to improve the exhaust gas purification systems, in particular, recirculation systems, use of gas fuel - after the adoption of the hourly Safety Manual for ships using gas as fuel and other innovation projects and technology expertise by the Maritime Safety Committee (MSC) of IMO at its 86th session. The rule, known as "IMO 2020," limits the sulfur content of fuel oil used aboard ships operating outside designated emission control zones to 0.50% m/m (mass by weight) - a significant reduction from the previous limit of 3.5%. In certain emission control zones, the limits were already stricter

(0.10%). This new limit became mandatory after an amendment to Annex VI of The International Convention for the Prevention of Pollution from Ships (MARPOL).

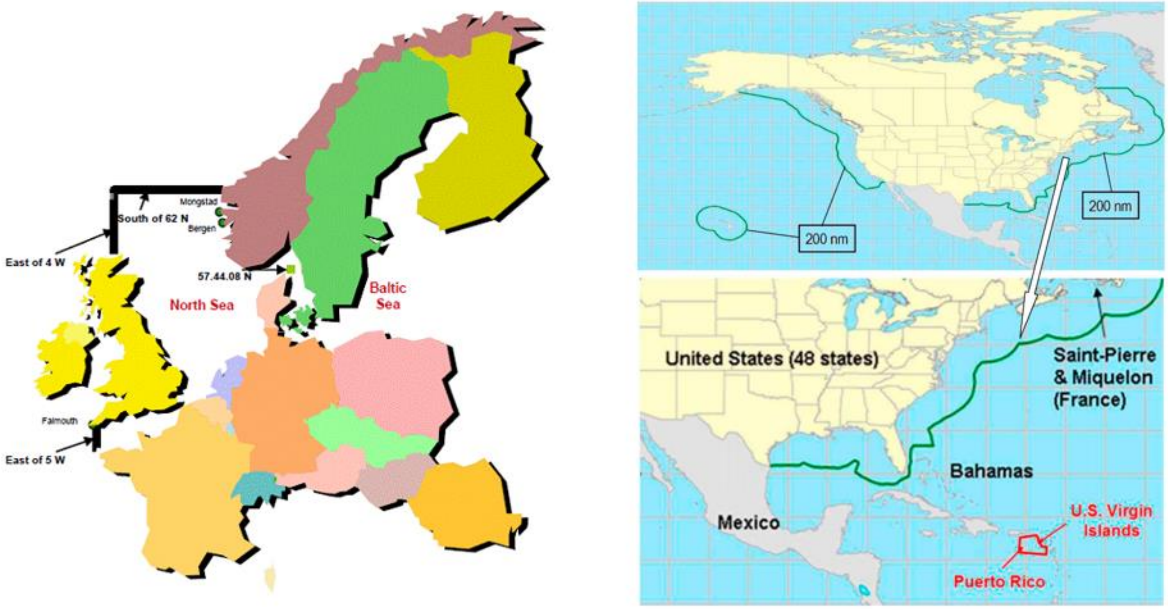


Fig. 1. Specific emission control areas
(EECA and NAECA)

The reduction of greenhouse gas emissions from ships is regulated by Annex VI (Revised) to the Convention "Regulations for the Prevention of Air Pollution from Ships" and the IMO report of States Parties to the "greenhouse gas" problem and strategies to reduce their emissions. The first IMO report noted a small fraction (1.8%) of the world's total greenhouse gas emissions from ships. Operational measures to reduce emissions became the new rules for the construction of ships, compared to modernization, which relates to the propulsion system: hull, engines, and propellers aimed at reducing energy consumption. Emissions of CO_2 from shipping for 2021 were up 4.9% from 2020 and higher than in 2019, citing data from Simpson Spence Young (SSY), a U.K. company. The largest increase in CO_2 emissions was recorded in the LPG carriers segment. The main reasons were the delivery of new ships and high demand. In the segment of bulk carriers and container carriers, these factors added an increase in the route and congestion in the ports. The global scale of emissions is as follows: electric power - 35%; agriculture - 24%, industry (factories, plants, and construction) - 21%; transport - 14%, residential sector - 6%; while water transport including supply and fishing vessels - 3.3% (Figure 2).

Since 2007, CO_2 emissions from ships began to increase by 17.5% and reached 1,019 million tons. Another later IMO report on "greenhouse gases" was considered at the 59th session of the Marine Environment Protection Committee. It presented a projection of CO_2 emissions from ships from 2007 to 2050 with an expectation of about 2,500-3,000 million tons per year by 2050. Marine transportation emits about 940 million tons of CO_2 per year and is responsible for about 2.5% of global greenhouse gas emissions (according to the 3rd IMO GHG study). These emissions are predicted to increase significantly unless urgent action is taken to reduce them. According to the 3rd IMO GHG study, emissions from shipping could increase from 50% to 250% by 2050 under a "business as usual" scenario, undermining the goals of the Paris

Agreement. It was agreed that the reduction of the level of emissions should be achieved by using market mechanisms in the form of the tax on fuel or trade in quotas for emissions. Thus, this article studies approaches to improve the environmental and energy efficiency of the ship on the example of the determination of energy efficiency for particular types of merchant ships.

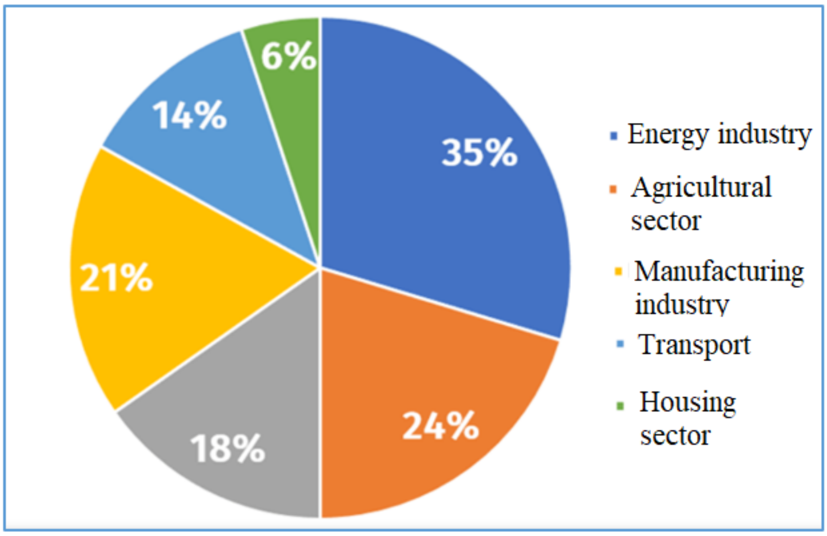


Fig. 2. Global scale of emissions

2.1. Measures to improve environmental and energy performance of vessels

An important economical measure to improve the energy efficiency of new ships is the mandatory Energy Efficiency Design Index (EEDI), a complex formula which can be applied to most types and sizes of ships:

$$EEDI = \frac{\text{Impact to environment}}{\text{Benefit for society}} \tag{1}$$

The coefficient should include CO_2 emissions as a cost, and the benefits should include cargo capacity and transport operations. Technical and operational measures to reduce greenhouse gas emissions include the Ship Energy Efficiency Management Plan (SEEMP) for all ships (new and existing) and the Energy Efficiency Operational Indicator (EEOI) similar to EEDI, the calculation reflects the ratio of carbon emissions and useful work performed (transported energy).

Ship energy efficiency plan includes:

- Improved voyage planning (guiding by the most advantageous routes, considering the weather, operating conditions and economic running close to the schedule);
- Optimization of speed, power, and main engine operation;
- Optimization of ship management (ballast, use of steering gear and autopilot);
- Improved fleet management;
- Improved cargo operations;
- Management of the ship's energy efficiency.

The EEOI of a vessel (new and in service) establishes the relationship between fuel consumption (tons), cargo quantity (tons), and the vessel's voyage route (miles):

$$EEOI = \frac{(\text{fuel conusmed} \times \text{Cf})}{(\text{cargo carrierd}) \times (\text{distance travelled})} \tag{2}$$

The 59th session of the Marine Environment Protection Committee decided:

- for new ships, the interim Energy Efficiency Design Index (EEDI) Guidelines, as well as the interim Voluntary Energy Efficiency Design Index (EEDI) Validation Guidelines;
- for all ships (new and existing) - guidelines for the preparation of the Ship Energy Efficiency Plan (SEEMP), as well as guidelines for the voluntary use of the Energy Efficiency Design Index for Ships (EEDI). MARPOL 73/78, Annex VI, they have converted the ship engines from sulfurous fuel (HSFO) to low-sulfur ship fuel (LSFO).

Expert evaluation of sources, factors and elements of ship energy efficiency improvement is presented in Table 1. The following are observed: higher fuel prices, the need for investment to adapt the fuel system of engines, problems of preserving engine life due to the deterioration of lubricating properties of LSFO-fuel, as well as difficulties in bunkering ships due to the scarcity and high cost of LSFO-fuel. Technologies for the purification of engine exhaust gases from SOx have not been used because of their problematic nature. Refrigeration and air conditioning equipment was changed from Freon R12 and R22 to Freon R404.

Tab. 1

Assessment of the prospective emission reduction potential

Ship's life cycle	Measures, Items	Reduction of CO_2 level, %	Total, %	Grand total, %
Design, construction (new ships)	Concept, speed and power	2 - 50	10 - 50	25 - 75
	Hull and superstructure	2 - 20		
	Power and propulsion systems	0.5 - 5		
	Fuel with low S	0.5 - 5		
	Renewable power source	1 - 10		
	Reduction of CO_2 in exhaust gases	0		
Operation (all ships)	Fleet management, logistics and stimulation	5 - 50	10 - 50	
	Voyage optimization	1 - 10		
	Energy Efficiency Management	1 - 10		

The main problem in fulfilling these requirements arises with the reduction of SOx, which forces ships to consume at least fuel, operating at reduced speeds, as well as attempts to fully connect the ship to shore power sources. There is a shortage of power and special transformers are required. There is an acute shortage of "know-how" technologies for fuel preparation of shipboard heavy fuel HFO. As an example, given the experience of using silicone paints for painting ship hulls, which for a vessel of 25,000 tons deadweight costs about 300,000 euros.

This coating requires the ship to be in running order all the time. Otherwise, the underwater part of the ship quickly grows by algae (silt), and when docked, the hull must be exposed to as little sunlight as possible to stimulate anti-fouling. When applying a new silicone layer, the primary layer must always be removed, which is technologically difficult and time-consuming. If the primary silicone layer remains, the new layer simply will not adhere to the vessel's hull, as a result, silicone coatings are economically efficient.

Mitsubishi Heavy Industries Ltd in Japan developed a conceptual design of a Panamax class container ship «MALS-14000CS», achieving a reduction of CO_2 emissions by 35%. The ship is equipped with the Mitsubishi Air Lubrication System (MALS) that directs air under the bottom of the hull, thus, by decreasing water resistance, it reduced CO_2 emissions by 10% compared to existing types of ships. Additional reduction of CO_2 emissions by 20% is achieved by changing the hull shape with the bridge located in the aerodynamic bow, chimney in the stern, and containers stowed under the living quarters in a newly designed high-performance low-resistance hull shape. The use of an automated twin-screw propulsion system with two engines and a waste heat recovery system reduces CO_2 emissions by a further 5%. The rest is made possible by the installation of exhaust energy recovery turbochargers with an electric generator integrated on one axis, which can operate in electric motor mode. Thus, from the ecological position, the use of thermal power plants, as well as the entire transport industry, is an inevitable problem, without which it is difficult to imagine modern civilization; however, it requires a huge intellectual effort and new approaches.

Further improvement of environmental friendliness of cargo transportation is aimed at the reduction of material and financial costs to the barest minimum. For ship power plants, this means a maximum reduction of non-circulating energy and material flows when a ship performs the mechanical work of changing the spatial location of the transported goods. The main factors of non-reversibility are losses of internal energy of a working body when generating mechanical energy and mechanical friction losses in the ship's hydraulic propulsion complex.

2.2. Implementation of Energy Efficiency Design Index (EEDI)

Energy Efficiency Design Index *(hereinafter referred to as -* $K_{KE(p)}$) during the inspection should not exceed the level of the boundary allowable base value for a vessel of the same type.

This approach, due to the introduction of new technological links, will allow the use of more economical engines, utilize waste heat, use alternative energy sources, and increase tonnage and design speed due to the optimization of ship hull shapes and propulsion system operation.

The K_{KE} is calculated according to the general method set out by IMO in MEPC 62/24/Add.1, and then the ship is inspected by the maritime administration of the country or its competent authority by the Registry of Shipping. After a successful inspection, the ship is issued the International Certificate of Energy Efficiency.

IMO Resolution MERS.203(62) is implemented in the design, construction and operation of ships. This work studied the use of a set of actions and methods of K_{KE} calculations, namely:

- Implementation of the MERC.1 Circ. 681 into the technical documentation;
- Use of the *K*KE calculation algorithm;
- Verification of the reliability of the calculations.

The first task is to use the working model by transforming the calculation formulas, tables and graphs into an analytical form, which is carried out in the following order.

The maximum value of K_{KE} (max) (on the baseline) is determined by a static empirical formula depending on the ship type (for 2.25 -2.31 according to MARPOL) and its deadweight:

$$K_{KE(MAX)} = a_i D_{w(i)(j)}^{-c_i}, \tag{2}$$

where *ai*, *ci* - empirical dimensionless coefficients of the i-th ship type; $i = [\overline{1...7}]$, $D_{w(i)(j)}$ - j-th deadweight of the i-th ship type, $D_{w(i)(j)} \in \left[400; D_{w(\max)(i)} T\right]$

And,

$$a_i = \begin{cases} 961{,}8 \text{ for } i = 1 \text{ (2.25) - bulk carrier,} \\ 1120 \text{ for } i = 2 \text{ (2.26) - gas carrier,} \\ 1218 \text{ for } i = 3 \text{ (2.27) - tanker,} \\ 174{,}2 \text{ for } i = 4 \text{ (2.28) - container carrier,} \\ 107{,}5 \text{ for } i = 5 \text{ (2.29) - multi purpose ship,} \\ 227 \text{ for } i = 6 \text{ (2.30) - reefer ship,} \\ 1219 \text{ for } i = 7 \text{ (2.31) - combination carrier;} \end{cases} \tag{3}$$

$$c_i = \begin{cases} 0{,}477 \text{ for } i = 1 \text{ (2.25) - bulk carrier,} \\ 0{,}456 \text{ for } i = 2 \text{ (2.26) - gas carrier,} \\ 0{,}488 \text{ for } i = 3 \text{ (2.27) - tanker,} \\ 0{,}201 \text{ for } i = 4 \text{ (2.28) - container carrier,} \\ 0{,}216 \text{ for } i = 5 \text{ (2.29) - multi purpose ship,} \\ 0{,}244 \text{ for } i = 6 \text{ (2.30) - reefer ship,} \\ 0{,}488 \text{ for } i = 7 \text{ (2.31) - combination carrier.} \end{cases} \tag{4}$$

To create the curve described by the equation (3), value $Dw_{(j)}$ changes from $Dw_{(\min)} = 400$ т to the maximum value $Dw_{(\max)}$ for a given type of vessel, the magnitude and value of the deadweight of the vessel in question $Dw_{(c)}$ with a step $\Delta dw_{(f)}$ equal to $0.02Dw_{(\max)}$.

Required index of energy efficiency design of the ship $K_{KE_{(T)}}$ considers the degree of E (%) improving the energy efficiency (environmental friendliness) of the ship:

$$K_{KE_{(T)}} = (1 - 0{,}01E) K'_{KE_{(MAX)}}, \tag{5}$$

Where $K'_{KE_{(\max)}}$ - maximum value of $K_{KE(\max)}$ at $D_{w(i)}$ of this ship.

The value E is a piecewise continuous function of three variables: ship type $i = [\overline{1...7}]$; the deadweight of the particular ship $Dw_{(j)(i)}$ and temporal period at $z = \left[\overline{1...4}\right]$. Moreover, the period of $\tau_1 \in$ [1.01.2013; 31.12.2014], $\tau_2 \in$ [1.01.2015; 31.12.2019], $\tau_3 \in$ [1.01.2020; 31.12.2024], $\tau_4 \in$ [1.01.2025; ∞].

$K_{KE(p)}$, as a calculation indicator of greenhouse gas emission, is a ratio of the mass of carbon dioxide (M_{CO2}) in the gas exhausted by the ship's thermal engines to the work performed by the ship to move the cargo, g_{CO_2} / (t·miles):

$$K_{KE(p)} = \left(\prod_{q=1}^{M} f_{hq} \sum_{k=1}^{nME} \left(P_{ME(k)} C_{FME(k)} SFC_{ME(k)} \right) + \left(P_{AE} C_{F(AE)} STC_{AE} \right) \right) + \\ + \prod_{q=1}^{M} f_{hq} \sum_{k=1}^{nPG} P_{PG(k)} - \sum_{k=1}^{nr} \left(f_{r(k)} P_{AEr(k)} \right) C_{FAE} S_{AE} + \\ + \sum_{k=1}^{nr} \left(\left(f_{r(k)} P_{MEr(k)} \right) C_{FME} S_{ME} \right) \Big/ \left(f_{Dw} D_w V_{ref} f_w \right), \quad (6)$$

where CF - the mass content of CO_2 at complete combustion of carbon in the fuel (Table 2).

Tab. 2

Characteristics of the fuels used by ships

№	Fuel type	Grade	Carbon dioxide, g/l	*CF*
1	Diesel/Gas Oil	ISO 8217	0.87	3.21
2	Light Fuel Oil (LFQ)	ISO 8217	0.86	3.15
3	Heavy Fuel Oil (HFO)	ISO 8217	0.85	3.11
4	Liquefied Petroleum Gas (LPG)	Propane Butane	0.82 – 0.83	3.00 – 3.03
5	Liquefied Natural Gas (LNG)	–	0.75	2.75

$Vref$ - operational speed of the ship, knots;

$Dw_{(i)(j)}$ - for container ships is 65% of the deadweight of the ship;

$P_{(x)}$ - total capacity of main engine (PME) and auxiliary (PAE) engines, kW;

$$PME_{(i)} = 0.75MCRME_{(i)} - PPS_{(i)}, \quad (7)$$

Here $PPS_{(i)}$ - 0.75 part of the output power of each installed halogen generator, divided by the efficiency of the halogen generator, kW;

$MCRME_{(i)}$ - maximum continuous power of the i-th heat engine, KW;

$PPG_{(i)}$ - 0.75 part of the nominal capacity of each generator engine, divided by the average efficiency of the electric generator, kW, (in case of joint operation of the shaft and electric generators $PPS_{(i)} + PPG_{(i)}$, the following diagram should be considered in the calculations);

$Pmer_{(i)}$ - 0.75 part of the power of the main engine, reduced as a result of the introduction of innovative energy-efficient technologies and mechanisms, kW;

$P_{AEr(i)}$ - power of auxiliary engines reduced due to innovations in the field of electric energy efficiency technology, kW;

P_{AE} - The power of the auxiliary engines required to maintain the continuous maximum running load, including the necessary load for the propulsion system and common needs, but not including the load for the propulsion system: steering equipment, pumps for cargo and ballast transfer, as well as cargo handling equipment (operating refrigeration systems and/or cargo hold fans) of a fully laden ship at high speed (Vref):

$$P_{AE} = \begin{cases} 0{,}025 \sum_{i=1}^{n_{(ME)}} MCR_{ME_{(i)}} + 250 & \text{при } MCR_{ME} > 10000 \text{ кВт} \\ 0{,}05 \sum_{i=1}^{n_{(ME)}} MCR_{ME_{(i)}} & \text{при } MCR_{ME} < 10000 \text{ кВт} \end{cases} \quad (8)$$

$S_{(x)}$ - engine specific fuel consumption, g/kWh, for engines meeting the E2 or EU NOx test cycle of the 2008 Technical Code, specific fuel consumption; $S_{ME(\mathrm{i})}$ recorded in the EIAPP (engine international air pollution certificate) for 75% of the MCR engine capacity or torque ratings, for engines, to test cycle category D2 or C1 under NOx Test Code 2008, the total fuel consumption rate $S_{AE(\mathrm{i})}$ is recorded on the EIAPP statement for 50% of the MCR capacity or on the torque gauge, for engines which do not have an EIAPP certificate and have a capacity lower than 130 kW, the S value is determined by the manufacturer and must be used by the competent authority for the approval of the International Energy Performance Certificate;

f_h - correction factor for certain vessel components (for ice-class vessels this factor is selected from MEPC.1/Circ.681 ANNEX VI, but for all other types of vessels it is taken as one if there are no additional components that increase the resistance to motion);

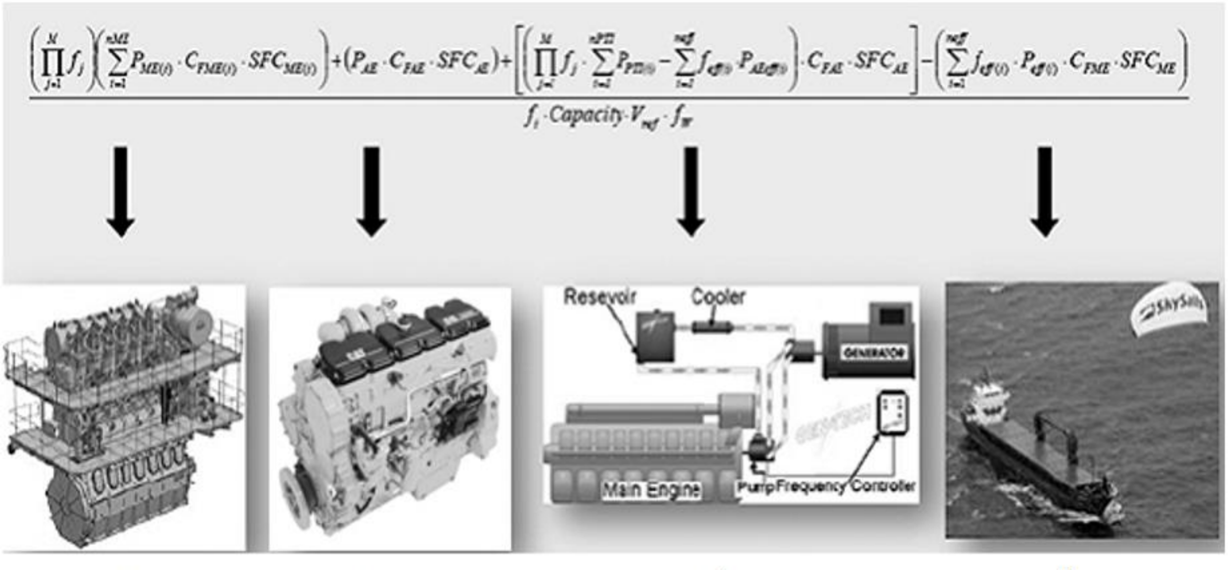
fw - the rate-free coefficient, which indicates the reduction of the ship's speed in rough and rolling conditions (to be determined by sea trials, or by calculation, or taken as 1 before specification);

$fr_{(i)}$ - coefficient of availability of each innovative energy-efficient technology, taken equal to 1 for heat recovery systems;

fdw - coefficient of cargo capacity, for non-ice class ships is taken as 1.

Formula (6) is not applicable to diesel-electric propulsion systems, turbo-propulsion systems and hybrid propulsion systems because it requires additional clarifications and approaches.

Formula (6) is illustrated below (Figure 3).



a) b) c) d)

Fig 3. Components of ship power plants, which influence the energy efficiency of a ship: a - main engine; b - auxiliary engine; d - energy-saving technologies for auxiliary units: c, d - energy-saving technologies for main units

In general, the Energy Efficiency Design Index is directly proportional to the fuel consumption by the ship, the capacity, the efficiency of the main and auxiliary engines, the methods of heat utilization, the capacity of the shaft generator and its efficiency, as well as other energy-saving design features and the proportional work of the vessel during the period of cargo transportation.

Analysis of previous calculations of the energy efficiency index made in some countries for different types and sizes of ships showed the applicability of the IMO method. The calculations showed their effectiveness for dry and container carriers with deadweight over 5000 tons, tankers, gas carriers and refrigerator ships with deadweight over 2000 tons, Ro-Ro ships with deadweight over 15000 tons and energy efficiency measures for larger ships.

3. CONCLUSION

Finally, it should be noted that the energy efficiency of maritime transport, in general, is higher compared to other modes of transport, so will consistently grow incentives and regulations aimed at improving the energy efficiency of ships. The analysis of the main tools of energy efficiency management of the ship demonstrates the implementation of effective ways to save energy on board ships through a comprehensive assessment and prediction of efficiency and reducing the carbon footprint in the environment. Regulatory requirements for energy efficiency management raise industry standards for maritime transportation facilities, hence improving measures aimed at improving the energy efficiency of ships primarily due to the reduction of carbon dioxide emissions into the atmosphere, among the top priorities. A separate place is occupied by the cost of implementation of new and more effective technologies for the modernization of existing ships to improve their environmental and economic performance, so the listed measures require the development of better and more substantial means and methods of energy efficiency.

Development of operative measures to increase ship operation effectiveness is undoubtedly an extremely urgent task requiring additional research and implementation of the latest technologies, one of which can be the use of integrated decision support systems aimed at the reduction of both fuel consumption and hazardous substance emissions. Presently, a set of technologies for improving the energy efficiency of ships has already been developed and successfully implemented. The focus is on the ship hull design, power regeneration, fuel quality and consumption levels, and shipboard operational measures but these means and operational methods still require to be improved in each area to achieve the maximum level of operational efficiency for existing and future ships.

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