

Ships' energy efficiency management: organizational and economic aspect

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Abstract. Maritime transport plays an important role in economic development of society, because it carries about 85% of goods, but it consumes a significant amount of fuel resources, which has a serious impact on air pollution. Millions of tons of nitrogen oxides, sulfur oxides, soot, heavy metal compounds and water vapor are released into atmosphere each year. These factors influence constant search for more effective methods to reduce toxicity of exhaust gases and develop organizational and economic conditions for fuel usage.

1 Introduction

Despite the fact that maritime transport compares favourably with other types of transport in regards to profitability, it is also the first in regards to harmful gases emissions into atmosphere and environmental pollution. Marine vessels use heavy fuel, which contains a significant number of heavy and dangerous metals, and it has a significant impact on air and coastline pollution.

Annex VI (Rules for Air Pollution Prevention from Ships) to the International Convention for the Prevention of Pollution from Ships (MARPOL) 73/78 was implemented on 19 May 2005. Two sections are of the greatest importance for practice: Regulation 13, which establishes limits on nitrogen oxides (NO) emissions from marine diesel engines, and Regulation 14, which establishes limits on the sulfur content of marine fuels [1]. In October 2008, the 58th session of the International Maritime Organization (IMO) adopted a new version of Annex VI [2]. The new version of the rules establishes gradual (Tier I - Tier III) introduction of new standards with increasing requirements for them.

Harmful substances from ships that pollute marine environment include:

- fuel oil, lube oils and sludges;
- ballast water with certain chemical and biological content;
- toxic, anti-fouling coating.

Harmful substances that pollute atmosphere include:

- exhaust gases of ship power engines;

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- emissions of ozone-depleting and other gases contained in ship mechanisms and devices [3].

At the beginning of 2015, amendments to the Convention came into force, which regulate sulfur amount in marine fuel used on ships whose routes pass in SECA areas (trading areas, which include the Baltic, North Seas and the English Channel, where ships must switch to low sulfur fuel). Mandatory requirements were adopted by the IMO Committee for the Protection of Marine Environment in 2016 by amending MARPOL Chapter 4 of Annex VI to the Regulations for the Prevention of Air Pollution from Ships [4].

According to the new Regulation 22A on collection and submission of data about actual consumption of marine fuel [5], vessels with a gross tonnage of 5,000 tons and more are required to collect data on the consumption of each type of fuel they use, as well as other additional data, including transport indicators. activities. These vessels account for approximately 85% of carbon emissions from international shipping.

From January 1, 2020, the requirements of the MARPOL Convention to prohibit the use of fuels with a sulfur content of more than 0.5% are extended throughout the whole international trading area [6].

2 Results

Fuel costs are the main cost item when using maritime transport. Therefore, it is important to develop a set of measures aimed at reducing fuel consumption in ships operation.

On the one hand, shipping time is one of the most important indicators of shipping company quality. But on the other hand, vessels operation at optimal speeds allows to achieve a significant reduction in fuel consumption and, as a consequence, a reduction in operating costs and emissions from ships. Therefore, when choosing the optimal vessels speed, it is important to maintain a balance between these two indicators.

River and especially sea vessels travel long distances with a set, usually constant speed, at which engines run in optimal mode for a long time, and therefore the exhaust gases contain a minimum of toxic substances.

Under normal conditions of operation, the main sources of pollution are ship power engines, as well as ballast water and water used for washing cargo tanks. First of all, ship power engines pollute atmosphere with exhaust gases, and then toxic substances partially or almost completely get into waters of rivers, seas and oceans accordingly, thus volumes polluting land and water environment are statistically connected. Using maritime transport data, it is possible to estimate amount of harmful emissions and damage to the environment. Maritime transport carries a large number of oil cargoes, which increases effect of water environment pollution due to significant hydrocarbons weathering. At the same time, tankers account for more than 50% of sea pollution with oil and oil products from maritime transport.

CO, CO₂, CH₄ gases are heavier than air and are accumulated on the surface of water environment. CO and gaseous hydrocarbon emissions from vessels power engines are involved in oxidative reactions and eventually converted to CO₂, which presence in atmosphere causes a greenhouse effect [7].

Considering that ship engines are the main consumers of high-sulfur heavy fuels - High-Sulphur Fuel Oil (HSFO), to regulate emissions of SO_x, in 2015 control area were introduced by IMO - Sulfur Emission Control Areas (SECA), which are shown in Fig. 1.

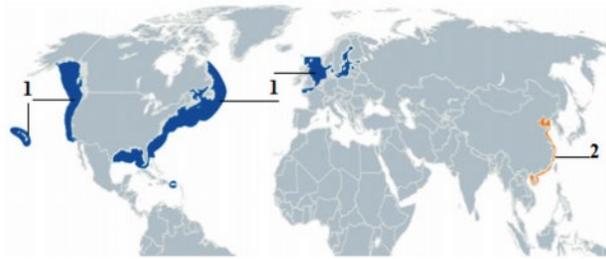


Fig. 1. SECA location and their limits: 1 - 0.1%; 2 - 0.5%.

The IMO, following allowability of using compatible low-oil fuel oil, has decided to globally limit the sulfur content of 0.5% for all trading areas, which came into force in 2020. This requirement is introduced in addition to the 0.1% sulfur limit in the North American and American areas of the Caribbean, North and Baltic Seas. In this case, vessels whose power engines are equipped with exhaust gas purification systems from sulfur content, will be allowed not to stop using HSFO (Table 1) [8].

Table 1. Regional and global sulfur regulators.

| Region | Sulfur content limit in fuel | Possibility to use scrubbers |
|---|--|--|
| All trading areas in international waters | 0,5 % | Yes |
| Control Areas (SECA) | 0,1 % | Yes |
| The European Union | 0,1 % in all port waters | In some countries, the use of open cycle is limited |
| China | 0,5 % в in national waters in the 12-mile area | Yes |
| California | 0,1 % in the 24-mile coastline area | No, only as an exception in the case of a separate application and additional research |

Essential amendment to the regulation is “Carriage ban on HSFO in the Fuel System”, with exception for vessels equipped with scrubbers. As earlier, it is allowed to carry HSFO as cargo, but it is forbidden to have HSFO in fuel system when scrubbers are not used. This amendment allows vessels using unsuitable fuel to be detained during Port State Control (PSC) without necessity to verify whether or not it has been used. It is expected that such amendments will significantly reduce possibility of violations of environmental legislation in international waters.

Expected increase in fuel costs, as many analysts of this sector predict, will lead to a certain slowdown in operating costs reduction. For the same reason, efforts will be focused on measures aimed at improving energy efficiency. Energy efficient vessels will be considered more competitive.

Vessels equipped with scrubbers can gain a significant competitive advantage. It is expected that vessels with scrubbers will initially be able to provide premium freight rates. However, if most vessels in a particular segment install scrubbers, the rates will be reduced as a result. Those vessels that will not be equipped with scrubber technology will be forced to reduce their rates to volatile levels and, ultimately, they may be pushed out of the market.

Therefore, it is very important for shipowners to monitor competition in their segment to ensure their dominance in the transport services market.

Significant investments necessary for competitiveness in the context of global sulfur oxide limits, combined with the costs associated with ballast water treatment systems, may lead to the situation when older vessels will become unprofitable for further operation, which may be the reason for higher disposal activity and then fleet renewal using modern, more efficient vessels. This trend may also accelerate introduction of alternative fuels, such as LNG [9].

Switching to distillate or MGO (Marine Gas Oil) fuel will mean a significant increase in fuel and lube oil costs, and may require modernization of power engines in terms of fuel preparation due to significantly low fuel viscosity. Fuel tanks previously used for HSFO must be thoroughly cleaned prior to MGO bunkering to avoid contamination problems and, as a result, non-compliance.

The main problem with the use of MGOs or distillates is related to their availability and cost in the fuel market. Many analysts believe [10] that in the first few months after new requirements introduction, the price difference between HSFO and distillates will be very high, which will significantly increase fuel cost and make alternatives financially attractive.

It is expected that low sulfur fuel blends will be available in the market as a variety of products. However, desulfurization engines are very expensive, and their installation, implementation and commissioning can take several years before they start operating at full capacity [11]. Thus, most refineries prefer to process higher grade fuels rather than invest in desulfurization systems. It can be assumed that to meet the demand will make new fuel mixtures that will meet the desired limit of sulfur content less than 0.5%, while reducing the cost by 10-15% compared to direct distillate fuels. The first fuel samples were presented at the end of 2018. It is likely that using new fuel mixtures will cause compatibility problems, and this will make fuel technological preparation a very important process for engine safe operation. Other problems associated with this type of fuel include long-term stability, impact on catalysts and relatively low flash point. Of great importance becomes quality control during bunkering, necessary to be confident that received fuel is in accordance with specification [12].

It is clear that using LNG as the main fuel will gain new benefits in context of new IMO limitations on sulfur emissions. LNG as marine fuel is technically proved solution, and bunkering infrastructure is developing rapidly around the world. Traditional fuel oils will remain the main fuel for most existing vessels in the near future, but commercial LNG opportunities are promising mainly for new ship designs, but in some cases also for conversion and modernization projects.

Thus, engine transferring to LNG should be carried out only on the basis of careful analysis of various information. In addition to commercial aspects, the main argument in favor of choosing LNG as a replacement for conventional fuel oils is a significant reduction in total air pollution from emissions of not only SO_x but also NO_x, as well as emissions of solids (Particulate Matter - PM).

Complete elimination of SO_x and PM emissions – is potential to reduce NO_x emissions by up to 85% - which contributes to using LNG, especially in control areas. In addition, LNG can reduce greenhouse gas emissions by 10-20% depending on engine technology. To sum up, using LNG has many benefits for both human health and the environment. In addition, it also has a positive effect on ship's Energy Efficiency Design Index (EEDI). [13].

Initial data for calculating emissions of harmful substances and their dispersion into atmosphere are the annual consumption of fuel and materials consumed by emission sources, including merchant navy vessels [14].

The maximum emission of *i*-th substance (g/s) from diesel engine is determined by formula:

$$M_i = (1/3600) \cdot eM_i \cdot Pe \quad , \quad (1)$$

where e_{Mi} – emission of i -th harmful substance per unit of useful diesel engine operation rated power mode, g/kWh; P_e – diesel engine operating power, whose value is taken from manufacturer's technical documentation, kW.

Under unstable economic situation in the world, maritime industry is facing changing operating conditions. In order to remain competitive in the market, most shipping companies are forced to take measures to improve energy efficiency. This is partly due to changes in oil and fuel prices. Therefore, a lot of attention of shipping companies is focused on developing measures to reduce fuel costs. These include the following: measures to organize transportation (vessels redistribution; routes integration; operating speed reduction; service cessation in less profitable areas; improvement of navigation conditions), measures for technological improvement (improvement of hull design; new technologies for marine engines; using alternative energy sources; computer technology).

Next, let us consider one of the most effective measures to reduce fuel costs, which lies in vessel operating speed reduction. To do this, we will analyze dependence of fuel consumption on vessel speed. Issues on dependence of fuel consumption on vessel speed and methods of choosing optimal operating speed was studied by many scientists, including [15-17].

Fuel savings during vessel operation might be achieved in several ways. One of them is to renew fleet with perfect vessels of new generation, which are equipped with modern economical engines. This way involves attracting significant investment. Another way to save fuel during vessel operation is to select and ensure optimal modes of marine engines operation, as well as to carry out various organizational and technical measures to save fuel and energy resources. Reducing speed during vessel operation allows the shipowner to reduce vessel operating costs, which is widely used in practice.

Based on known dependence of fuel consumption per day underway ($q_{underway}$) on vessel speed (V):

$$q_{underway} = \left(\frac{V}{V_{max}}\right)^a * (q_{max} - q_{min}) + q_{min}, \quad (4)$$

where a - constant parameter ($a=2,507849$ is set using the least squares method);

V_{max} - maximum vessel speed, knots;

q_{max} - fuel consumption at maximum speed, t / day;

q_{min} - fuel consumption at minimum speed, t / day,

it is possible to determine the most appropriate vessels speed modes.

We have made calculations of fuel oil and diesel fuel consumption dependence by bulk carriers underway (type Handysize) with deadweight ranging from 32 thousand tons to 43 thousand tons.

As it can be seen from Figure 2 and Figure 3, at speed range up to 12 knots, the lowest fuel consumption refers to vessel "D", however, at range of more than 12 knots – priority is taken by vessel "A". And diesel fuel consumption varies in the range: from 12 knots for vessel "C" to 14.5 knots for vessel "A".

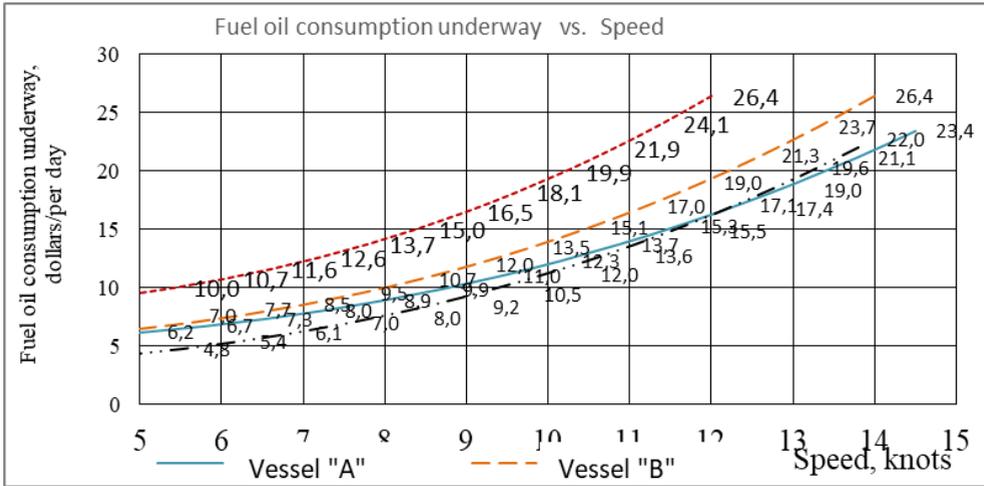


Fig. 2. Comparison of fuel oil consumption dependence on vessel speed for vessels under consideration.

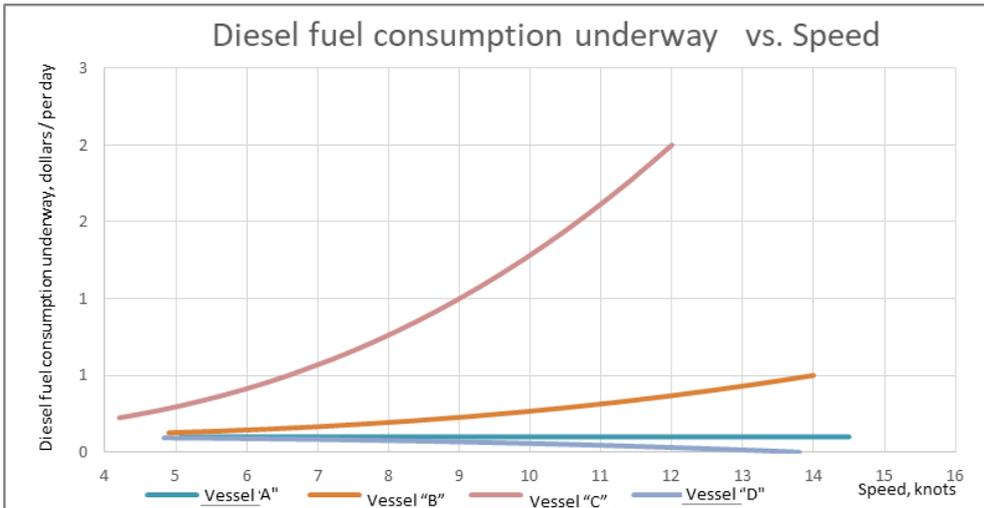


Fig. 3. Comparison of diesel fuel consumption dependence underway for vessels under consideration.

When choosing a vessel, you should also pay attention to the length of speed range at which vessel is optimally used. If vessel usage is optimal in a wide range of speeds, as in our case, for vessels “A”, “C” and “D”, shipping company in the future can provide additional flexibility in agreeing freight rates and shipping time through possibility of vessel efficient operation at different speeds, which also affects amount of harmful emissions into atmosphere and coastline areas [14].

3 Conclusions

It is important for maritime transport operation to reduce unit costs, the most important component of which is fuel costs and energy efficiency. Factors that determine rationalization process for their use can be divided into certain groups:

1. Technological factors of resources efficiency include measures related to improving transport production. The same group of factors includes increasing level of mechanization and automation, rational consumption of fuel oil and lube oil, reducing norms of their usage on the basis of modern experience.

2. Constructive economy factors include group of measures aimed at improving design solutions and calculation methods. Especially important for marine transport is to increase operational reliability, reduce mass and dimensions of engineering factors.

3. Organizational and economic factors include measures aimed at improving organizational and economic conditions of using fuel. The basis of these measures lies in improving norm setting and efficiency of fuel and energy resources, improving conditions of their storage, utilization of thermal energy.

To sum up, the basis for fuel and energy efficiency in maritime transport is development and implementation of energy-saving and environmental technologies and improving fuel management.

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