

Cost optimization of marine fuels consumption as important factor of control ship's sulfur and nitrogen oxides emissions

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Abstract

This paper proposes an efficient, objective method of optimizing fuel costs during the sea passage. The presented method based on data collection and calculations can be used in daily practice for masters of vessels and by ship's management divisions. The paper presents not only the use of the method for newly constructed but also for ships already in service. The biggest advantage of this method is that it does not need extra expenses to determine the fuel effectiveness in a changeable marine fuel market.

Introduction

Cost of marine fuels dominate over the other maritime transport expenses. This is due to, among other things, the introduction of requirements for Sulphur Oxide Emission Control Areas (SECA) and Nitrogen Oxides Emission Control Areas (NECA). IMO Resolution MEPC.203 (62) requires to introduce Marine Energy Efficiency Management Plans since January 1st. One of the most effective ways for existing ships to meet all of these requirements is the optimal use of fuel on board. In practice, this would mean for a shipping, inter alia, to determine the vessel's economy speed.

The world market of ships fuels based on the processing of crude oil forecasts a continuous increase in the price of bunker in relation to other costs incurred in shipping. The increase of bunker costs is also due to the implementation of international regulations limiting the sulfur content of marine fuels. In this case, there is an essential link – the price increases with a decrease in the sulfur content of marine fuel. The 3.5% standard of maximum sulfur content in the fuel binding in the past is gradually moving in the Baltic Sea Area to 0.1% standard on January 1, 2015. It means a surge in the cost of business for shipping in this region since that date.

For the operation of a ship the aim is to enlarge the profit level by reaching the highest freight with the lowest operational costs. Commercial success of the transport projects require to reduce important operating costs, especially in times of global crisis when shipping freight rates drop considerably on the market. Regardless of the operation costs of ships, the shipping company should always look for cost savings resulting from the “shore” part of their business. However, the ships expenses will be an essential component of the operating costs. Then, the next main component of the cost will be the charges for fuel used by the ship. In this situation, for the success of the business it is particularly important ship's captain cooperation with the owner or charterer. The method described in this article allows to optimize ship's fuel consumption by a fast, low cost and efficient way and to ensure the economic success of the transport task.

Assumption of the method

On the one hand seagoing vessels are running at sea passages with two speed ranges corresponding with main engine settings:

1. Sea speed, usually a range of most likely used speed of the ship. The engine is running at optimal range of the load curve. Ship speed adjust-

ment in addition to the change of the main engine revolutions may also concern setting of variable pitch propeller.

2. Range of speeds less than the sea speed, so-called manoeuvre speed. At this range the set of the main engine will be reduced – lower setting of propeller's revolutions will be used and alternative lower angles of pitch propeller. Manoeuvring ship requires the activation of additional mechanisms in the engine room, needs additional power requirement. Ship energy security needs starting additional generator sets. Manoeuvring setting of the main engine causes the increase of the total consumption of marine fuels in spite of reduced speed.

On the other hand, there are several classifications of navigable waters. For the purposes of this paper, it is advisable to adopt the division of navigable waters as a non restricted and restricted areas [1]:

1. Non restricted areas (open waters) where the vessel is able to fairly freely choose its speed. The only significant external factors affecting the speed of the vessel are hydro and meteorological conditions. The capability of decision on the ship's speed on open waters can be an effective solution to the problem of optimization of fuel consumption.
2. Restricted areas where vessels usually navigate close to land. Ships traffic is regulated by a number of local and international rules, including those that affect the speed of the vessel. In such areas ships are forced to perform frequent by changing both manoeuvres the speed and the course. Other phenomena limiting propeller efficiency can be observed, among other things additional resistance to motion caused by shallow water effect [2]. Captain decisions during navigation in restricted areas are mainly motivated by safety of navigation. Economic considerations come therefore in the second place.

The presented classification of settings of the main engine and navigational areas allow to draw a conclusion that the area on which the ship's captain can have effective influence on the economical success is non restricted area where a ship is sailing with a sea speed. The conclusion drawn for this case can also be used for some parts of the sea passage on the restricted areas.

Object of research

The conditions presented in the paper occurs when a ship is operated directly by a Shipping Company. The owner can always specify fixed

daily costs of the vessel, described for the purpose of this paper as day costs. They include, among other things, technical costs, crew and any additional costs directly related to the transport of cargo (port charges, pilots, tugs etc.). It is necessary to take into consideration that some of the technical costs are not exactly fixed. For example running of the main engine on the low revolutions generate some cost of additional maintenance. Lower revolutions cause lower burning temperature at the cylinder and in consequence raise the quantity of not burned hydrocarbons accumulating on internal parts of the main engine. The result is for example the increased wear of piston rings. There are also shortened periods of routine maintenance and increase in costs. There are no major obstacles for the owner to estimate the rising cost of the main engine maintenance based on computerized maintenance and purchase systems like SpecTec's AMOS. But for the purpose of this article it has been assumed that daily costs are fixed, independent of the setting of the main engine revolutions. Daily costs should also include appropriate part of on shore owner activities.

In addition to these generally considered fixed daily costs of the ship, there is a group of costs related to the amount of fuel burned. There is no doubt that there is a strong correlation between the speed of the vessel and the daily amount of fuel burned. This correlation is valid also for speed and the daily cost of fuel burned.

Knowledge of the daily cost of the ship and the daily cost of fuel burned allow for the best affreightment decision. Estimated daily profit achieved in the carriage of cargo cannot be less than the sum of the daily cost of the vessel and cost of burned fuel. On the basis of the knowledge of the total daily cost of the vessel, the decision to hire a ship to the Time Charters may be taken. The difference between the daily cost and the daily charter rate will be a profit for the owner.

The calculations presented in this article have been done for universal bulk carrier with a deadweight of 38 thousand tons, the length of 190 m and the width of 29 m.

Experimental model of ship's fuel daily consumption

The ship's captain in every sea passage situation has the ability to take a decision on the ship's speed. The theoretical analysis shows that daily consumption increases with the propeller revolutions to the third power. Then the ship's speed should increase in the proportion to the increase of screw turns. Therefore, in order to describe the

daily consumption and speed of the vessel, binomial power model should be applied:

$$\text{consME}(V) = a V^b + \varepsilon \quad (1)$$

where:

- consME – daily fuel consumption of the main engine for speed V [t];
- V – speed of the vessel for which consME is determined [kts];
- a, b – parameters of the model;
- ε – the error of term power regression function.

For the previously presented theoretical considerations, exponent b should be set to three. Because of mechanical losses and due the propeller slip, vessel speed increases more slowly than the screw revolutions. Practical dependence of binding daily consumption speed of the vessel will have an exponent value slightly greater than three. To recapitulate, the value of the parameter b of the power regression functions should be in the range from 3 to 4. Regression parameters a and b can be determined by known methods using a widely available statistical analysis software.

Acquisition of data and determination of the fuel consumption curve

In order to create a model based on the power regression method of least squares, it is necessary to meet the assumptions of the random component ε of equation (1). The values of each error ε should be independent random variables having a normal distribution with mean 0, or the expected value of 0, and a constant variance, independent of the value of the variable V measurement [3]. In order to establish normal distribution of ε , it is necessary to obtain a large number of data pairs consME – V . As mentioned previously, the vessel speed is carried on the sea passages in the optimum range of the main engine load curve. For most of the ship, speed range will be between 10 to 15 knots for the engine load between 30 to 75 percent. In sea practice, due to the limited duration of the experiment and in order to avoid the additional cost, it is difficult to get more than 4 to 5 measuring connecting ship speed V and fuel consumption consME. Typically, data at intervals of about 1 knots of value V are recorded.

In view of this fact, the regression equation based on a built achievable in practice, four or five pairs of data, the regression model cannot be built. Determined equation can be used for descriptive purposes only. Such an approach is sufficient to draw practical conclusions. Generally, available computer's spreadsheets allow to easily determine

the equation describing the relationship consME as a function of the ship's speed V . As it has previously been demonstrated, the regression of two-dimensional power law must be used for the description.

However, nothing stands in the way as far as completion of data collection over a long period of time is concerned, to build and analyze models of fuel consumption as a function of speed. But the long-term change which disturbances of the model has to be taken into consideration. Among other things, the influence on the model has the main engine efficiency change due to aging and interval between inspections. Deformation and fouling of the submerged part of the ship's hull are also significant factors. In practice, it turns out that it is better to build the current descriptive equations instead of determining the not always valid and current model.

Due to hydrodynamics, ship speed strongly depends on the load condition. The consequence of mean draft increasing and simultaneously maintaining the same ship's speed is always the increase of daily consumption. For example, the differences between the main engine daily consumption for the fully loaded and the ship at ballast condition reach 30 percent.

This article presents the calculations carried out for the loaded ship. Similar considerations, made by the same algorithms can be carried out not only for ship at ballast but also for other intermediate loading conditions.

Graph and analytical formula describing consME depending on V for modeled ship at full loading condition is shown on figure 1.

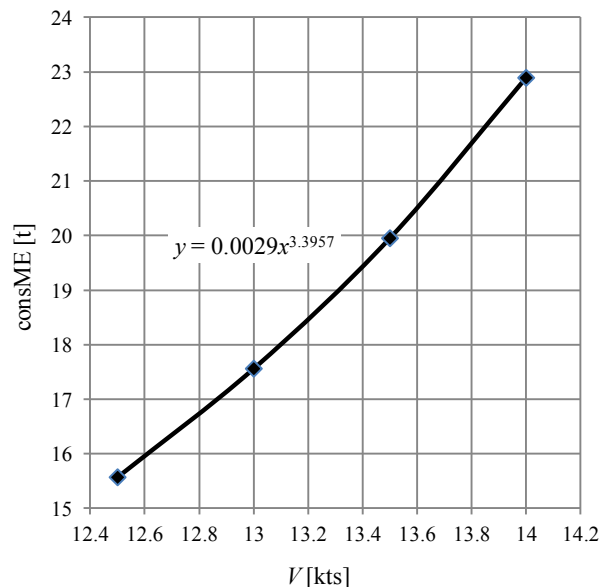


Fig. 1. Function $\text{consME}(V)$ of fully loaded vessel

In practice V values can be obtained from the log, or in the absence of the currents also from the satellite receiver GPS. The value of consME can be obtained from counters of the fuel flow transported to the main engine. Typically, these data are available only for the engine crew. The appliance solutions available also enable to read the parameters directly on the bridge. The figure 2 shows an example of a device installed in the ship's engine control room, where it is possible to read the amount of fuel supplied to the main engine.



Fig. 2. Fuel flow meter showing current fuel consumption of $1.06 \text{ m}^3/\text{h}$

During the voyages such favorable hydro and meteorological conditions can be found that enable reading of not deformatted parameters of consME and V . However, such experiments are performed only when a vessel does not bear additional costs resulting from the extension of the route or the longer voyage time. Particularly favorable circumstances are when the ship accelerates to the speed at sea after leaving the port or slows before entrance to the port. Then for some intermediate speeds between manoeuvring speed to sea speed, it is necessary to write down two pairs of parameters: speed V and the main engine fuel consumption consME . To minimize errors an experiment both for the acceleration and deceleration phases has been conducted.

Optimizing the cost of ship's fuel during a sea voyage

In order to present the method to optimize the cost of ship's fuel it is necessary to define the cost of one nautical mile passage which borne by the owner – $\text{mileCost}(V)$. This relation is represented by the formula:

$$\text{mileCost}(V) = \frac{\text{consME} \cdot \text{priceHFO}}{24 \cdot V} + \frac{\text{consAE} \cdot \text{priceMGO}}{24 \cdot V} + \frac{\text{dayCost}}{24 \cdot V} \quad (2)$$

where:

consME – daily fuel consumption of the main engine for ship speed V [t];

priceHFO – the price of heavy fuel oil for main engine [USD / t];

consAE – daily fuel consumption of the auxiliary engines (power generators) [t];

priceMGO – the price of marine gas oil for the auxiliary engines [USD/ t];

V – speed of the vessel for which it is determined consME [kts];

dayCost – the owner's daily cost [USD].

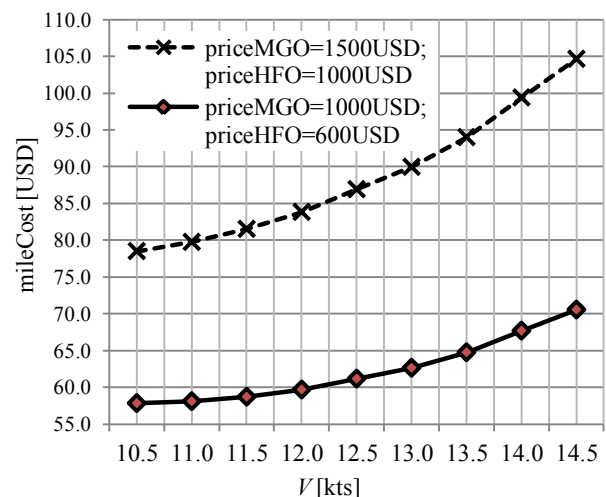


Fig. 3. Cost of one nautical mile passage as function of ship's speed, owner's dayCost 6000 USD

From figure 3 the effects of irrational decisions of ship's management can be directly read off. For lower fuel prices and the low owner's daily cost 6000 USD, forced by fleet management high value of sea speed ship costs abt. \$ 10 by every nautical mile of the passage. This seemingly small amount can no longer be underestimated, taking into consideration several thousand miles of sea passages. There are two positive effects, the costs are minimized and the consumption of fuel is reduced.

Figures 3, 4 and 5 show the graphic description of the equation (2) obtained for the modeled ship. Four pairs of input data $\text{consME} - V$ on board the full loaded vessel after leaving the port are recorded. The calculations were performed for two samples of data sets:

- 1) $\text{priceHFO} - 600 \text{ USD / t}$, $\text{consAE} - 3 \text{ t}$,
 $\text{priceMGO} - 1000 \text{ USD / t}$,
- 2) $\text{priceHFO} - 1000 \text{ USD / t}$, $\text{consAE} - 3 \text{ t}$,
 $\text{priceMGO} - 1500 \text{ USD / t}$.

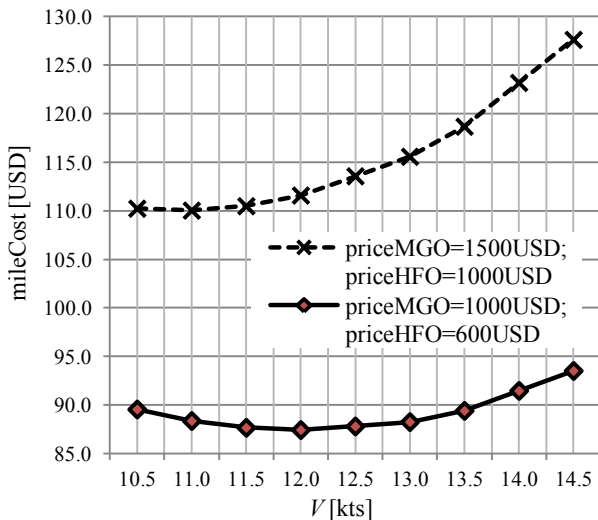


Fig. 4. Cost of one nautical mile passage as function of ship's speed, owner's *dayCost* 14000 USD

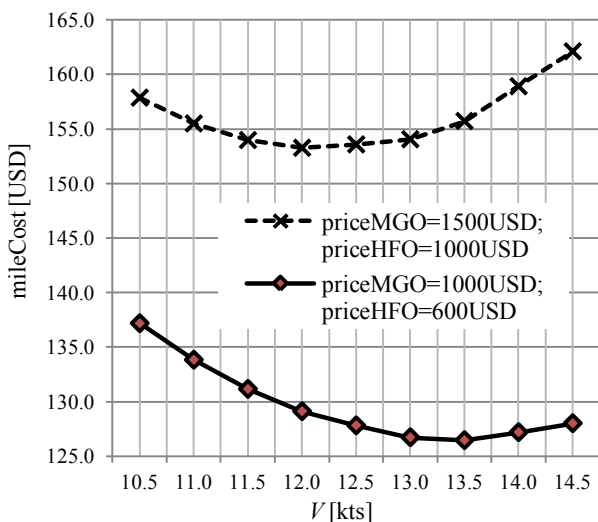


Fig. 5. Cost of one nautical mile passage as function of ship's speed, owner's *dayCost* 26000 USD

From the graphs presented on figures 3, 4, 5 optimum ship's speed can be read, where the cost of one nautical mile reaches minimum value. For example, at low owner's daily cost 6000 USD it is effective to plan the possible minimum ship's speed. Optimum ship's speed is going up parallel to increasing the value of owner's daily cost.

Broken white line on the figures present fuel price increase as an effect of introduce of new both Emission Control Areas. In this condition ship has to use mostly minimum sea speed to minimize cost of one mile passage. Presented bunker prices are not showing economic prediction, are used only for method's presentation.

The above calculation confirms the shipping company Maersk strategy called "slow steaming" – reducing the ships speed to minimum reasonable value. Based on paper presented method the analy-

sis of the optimization of fuel is available not only for shipping giants but also for small owner's companies.

One additional advantage of this method is the ability to optimize the costs of ships still in their construction stage. But it is necessary to obtain theoretical determination of the relation $\text{consME}(V)$ for the designed ship. The method to determine this relation is suggested in unpublished studies by MSc. Janusz Falkiewicz, an employee of Polish Steam Company Investment Department. For one of the ships in a design stage $\text{consME}(V)$ functions calculated theoretically were confirmed experimentally on ship leaving the building shipyard.

Conclusions

Simplicity, speed and flexibility of the proposed cost optimization method give great profits in terms of the continuous increase in the price of marine fuels. Without any real expenses, it is possible tracing nonstop of current function $\text{consME}(V)$, which is the base of the proposed method. This is particularly important, because the conditions of the ship are changing constantly and rapidly. As an example is fouling of underwater part of ship's hull on freshwater navigable areas, especially in tropical rivers or lakes connected to the ocean waters. Fouling due to a long layover may cause a decrease in vessel speed by up to ten percent. The method of optimizing the cost of fuel can also be used to demonstrate the economic sense of cleaning the underwater part of the hull of the ship.

Another problem of efficiency may also be solved by proposed method. The underwater part of hull is affected by continuous deformation which systematically increases hydro resistance. Also long-term aging of the main and auxiliary engines is not without effect on the ratio of fuel consumption and due to this fact decreases the effectiveness of ship's gears.

To ensure an economic success, it is essential that the owner should define operating speed and corresponding reverse per minutes of the main engine revolutions or pitch propeller setting. Optimal speed value should be calculated on the shore, on the basis of data obtained from the vessel and trade secret and not data available on board of the ship. On board of the ship captain will be obliged to continuously update pairs of data $\text{consME} - V$. It should be done in all conditions not generating additional expenses. The presented method of optimizing fuel costs allows the shipping company to adapt to the rapidly changing economic conditions in the shipping market.

The optimization of the consumption of fuels on board usually requires the lowest possible speed. That means less fuel consumption. This will be particularly important from January 1, 2015. From this date the use of expensive distillate fuels with a sulfur content less than 0.1% in Sulphur Oxide Emission Control Area is mandatory.

Annex VI of the MARPOL Convention in 2016 introduces emission control areas of nitrogen oxide. The presented method allows optimization of the fuel quantity based on the ship's speed. Main conclusions concerning high bunker prices is movement of the ship with minimum speed means lower main engine load. The lower engine load entails lower combustion temperature. Such situation could result in lower emissions of nitrogen oxides

in relation to the power obtained on board – ratio of gNO_2/kWh .

The approach proposed in the paper allows the owner not only to optimize the economic analysis of the project but also allows to make the initial calculation on how the ship may meet requirements of Nitrogen Oxide Emission Control Area in 2016.

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