

## Energy saving technologies for fishing vessels

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### Abstract

The paper presents an analysis of technologies usable at fishing vessels which ensure that fuel consumption by their power systems is reduced as well as the emission of exhaust gases. During the analysis the specificity of operational activities for fishing vessels and the International Maritime Organization (IMO) requirements have been taken into consideration. Energy saving technological, operational and logistic activities have been discussed. Forecast savings regarding fuel consumption upon application of technological innovations at fishing vessels have been presented.

### Introduction

In recent years technologies aimed at the reduction of power consumption and the emission of exhaust gases to the atmosphere by marine energetic systems have been implemented more broadly. It is related to the increasing prices of petroleum products used at ships (the cost of fuels, oils and lubricants constitute 50–80% of ship operational costs) and with the IMO requirements regarding environment protection. On 01.01.2014 the IMO introduced the requirement for new built ship to conform with the developed Energy Efficiency Design Indexes (EEDI). As far as the older vessels in operation are concerned it is advisable to implement technological changes during repairs and inspections in order to reduce fuel consumption and the emission of exhaust gases. Moreover, all ships being in operation and the new ones, are subject to the Ship Energy Efficiency Management Plan (SEEMP), which ensures optimal ship operation from the point of view of power consumption and hazards to environment. The obligation refers to ships over 400 GT and to the following types of ships: bulk carriers, gas carriers, tankers, container ships, general freight carriers, refrigerated freight ships and combination carriers [1, 2]

Considering the volume of fishing cutters belonging to the Polish fleet and the types of ships that are subject to the requirements it may be

concluded that the IMO regulations do not apply to this type of vessels. Long-term cooperation with shipowners demonstrates their considerable interests in obtaining the biggest savings in the amount of consumed fuel while providing suitable amount of mechanical power, electricity and heat energy that are essential for the execution of the operational activities of fishing vessels. Therefore, this paper furnishes an analysis of energy saving technologies feasible to be applied at fishing vessels in order to improve the Energy Efficiency Operational Indicator (EEOI), developed by IMO which may constitute a supplement to SEEMP. Although the regulations of IMO do not include fishing vessels, it shall be advisable to determine EEOI indexes for comparative purposes in that group of vessels as well as in order to compare with other ship types and to develop SEEMP. The analysis has been limited to EEOI due to the fact that the EU grants which are available to fishing vessels' owners cover merely the modernization of fishing vessels.

### EEOI as energy efficiency indicator for fishing vessels

A developed formula for determining  $EEOI_F$  for fishing vessels, having in regard the specificity of fishing vessels' operational activities and the relation recommended by IMO [1, 2] is as follows:

$$EEOI_F = \frac{\sum_j FC_j C_{Fj}}{m_{\text{cargo}} D} [\text{gCO}_2/\text{t}_{\text{cargo}}\text{Mm}] \quad (1)$$

where:

- $FC_j$  – is the mass (in grams) of consumed fuel by main and auxiliary engines and oil fired boilers at the execution of operational task;  
 $j$  – fuel type (there is one fuel type used at fishing vessels);  
 $C_{Fj}$  – conversion factor expressed by the relation of  $\text{CO}_2$  mass (tonnes) produced from the combusting of a tonne of  $j$  type fuel;  
 $m_{\text{freight}}$  – the mass of catch carried (tonnes);  
 $D$  – distance in nautical miles corresponding to the operational task performed.

At the Polish fishing fleet vessels only one type of fuel is used for internal combustion engines and oil fired boilers. The value of  $C_{Fj}$  conversion factor, according to IMO [1, 2], for the fuel, which is the closest type to the one, used by the Polish fishing fleet, equals to:

- Fuel name – Diesel/gas oil;  
 Fuel type – ISO 8217 DMX to DMC;  
 Carbon content – 87.5%;  
 $C_{Fj}$  – 3.206 [ $\text{tCO}_2/\text{t}_{\text{fuel}}$ ].

In case of fishing vessels,  $EEOI_F$  factors associates the amount of  $\text{CO}_2$  emitted to the atmosphere with the mass of consumed fuel and of fish caught and the distance sailed.

During an analysis of the formula (1) it may be concluded that the  $EEOI_F$  value strongly depends on the distance travelled by a vessel during an operational task and the amount of fish caught. The  $EEOI_F$  value will vary in different operational states i.e. during free sailing or trawling. For example, according to the formula (1) it is impractical to determine  $EEOI_F$  during free sailing to a fishery when the vessel is not carrying any fish. It seems advisable to determine  $EEOI_F$  for an operational task of the fishing vessel taking into consideration the entire distance travelled, the total mass of fuel consumed and fish caught.

The mass of fuel consumed is affected by the type of internal combustion engines installed at a vessel and the level of their technical and technological advancement related to the year of engines' production. Examples of unit fuel consumption for the rated power of medium-speed and high-speed internal combustion engines installed at fishing vessels according to a production year are presented in table 1. The engines of the power below 1000 kW were taken into consideration [3].

The research results' analysis of the operational power systems of the Polish fishing fleet [4]

Table 1. Specific fuel consumption for medium-speed and high-speed marine internal combustion engines according to a production year

Engine production year	Before 1984	1985–2000	2001–2010	After 2011
Specific fuel consumption $g_{MCR}$ [g/kWh]	225–250	205–220	195–210	190–205

allowed for an assessment of energy consumption for particular energy receivers (with respect to 100% chemical energy in fuel) [4]:

- Main drive 60–75%  
 Fishing gear (hydraulic drive) 10–15%  
 Electrical equipment 2–15%

Given the above analysis of the demand on energy at fishing vessels, it shall be concluded that the intention to reduce energy consumption and  $EEOI_F$  factor should be mainly concentrated on main drive systems.

However, a complex plan to reduce of energy consumption, and hence also for increasing the operational effectiveness of fishing vessels, should cover a number of activities which may include [5]:

- technological activities;
- operational activities;
- logistical activities.

### Energy saving technological activities

The most important innovative, technological activities referring to fishing vessels may include:

#### a) Optimization of hull's shape in order to reduce resistance

Hull's resistance is significantly affected by its dimensions and block coefficient and a ratio of the length and the width related to them. The EU regulations have imposed the requirements regarding the length of fishing vessels which are also applicable to the Polish fleet, adopting the thresholds of 12, 15 and 24 m [6, 7]. The necessity to provide appropriate hull capacity for cargo hold for fish, engine room, crew rooms, net storage rooms caused that fishing vessels, at limiting their length, are characterized by significant hull width. It affects the low value of the relation of the hull length to the hull width. Along with the decrease of the value, the hull resistance rises. The value of the relation of the hull length to the hull width for operated fishing vessels, within the scope of the hull length changes from 12 to 24 m, amends from 2.15 to 3.20 respectively [4, 7]. For other ship types the values of the relation are much higher e.g. ferries 6.0–7.5, warships 9–10.

The abovementioned legislation limitations and operational requirements contributed also to the fact that the vessels are also characterized by the high values of the hull block coefficient varying from 0.80 to 0.85 (only the hull block coefficient for ocean trawlers equals to from 0.50–0.55). The hull resistance rises with an increase of the block coefficient.

The low values of the relation of the length to the width and the high values of hull block coefficient for fishing vessels cause that the high values of a wake coefficient are generated (0.35–0.45). That may result in worsening propeller work conditions by decreasing its forward speed and efficiency and the risk of vibrations increases.

The impact of the relation of the hull length and its block coefficient on the hull resistance is proven by research executed in France. For the fishing vessels of the length of 12, 15, 17.5 and 24 m new hulls were designed without observing the requirements of EU regarding the hull length. Assumptions adopted to keep fishing capacity and free sailing speed. The hulls were lengthened from 15 to 20% and widened from 4–8%, so that the relation of the hull length to the hull width increased to the value in the range from 2.7 to 3.6 [7]. The decrease of the hull resistance is proven by the demand for propulsion power in the range from 10 to 25%. The increase of dimensions will also result in an improvement of navigation safety by the improvement of stability, floatability and freeboard height. Increasing the deck surface will improve work conditions for fishermen. Social area will be extended, too. Crew cabins may be located in areas less exposed to noise and vibrations.

The reduction of the hull resistance is significantly affected by the improvement of hydrodynamic flow around by installing inter alia bulbous bow, extending submerged stern part, optimal rudder systems. The modeling of holes in the hull, water flow in bow thrusters' tunnel and the selection of proper spots for galvanized electrodes installation will cause further reduction of the hull resistance.

#### **b) Improvement of propulsion system effectiveness**

Propulsion system optimization, from the energy consumption point of view, covers a number of issues among which are:

- **propeller selection** – when selecting a propeller for fishing vessels, the limited space above the stern should be taken into consideration as well as the required distances between the propeller and structural hull elements and the rudder and low vessel

immersion which prevents the installation of high efficiency propellers of large diameters.

The propeller effectiveness is also affected by the number of blades and their profiles. Using skewed blades (maximum angle of 45°) results in an increase of propeller surface area which will cause that thrust force increases when compared with a propeller of the same diameter without skewed blades. Cavitation intensity will also be reduced, in particular at the trailing edges and the blade tips;

- **propeller rotational velocity** – upon having selected the propeller diameter on the grounds of the available space behind the stern, propeller rotational velocity should be adjusted, which in the relation with the required propulsion power, has a decisive impact on the propeller performance. In order to select the propeller diameter and adjust its rotational velocity depending on the propulsion power there is a number of nomograms developed by the producers of propellers and drive systems;

- **selection of reduction gearbox** – in order to reach the required propeller rotational velocity a reduction gearbox should be used of the reduction ratio depending on the engine speed of installed main drive engines;

- **selection of main drive engine** – from a wide range of available medium and high speed engines for main propulsion installed at fishing vessels, one should select engines characterized by low unit fuel consumption, low exhaust gases emission indicators which are adjusted to be in operation constantly in the wide range of changes in power load. Providing engines with measurement and control equipment will facilitate control on current basis of the engine power load and fuel consumption. It is also advisable, whether supplying engines with alternative fuels is also possible e.g. biofuels, LNG;

- **improved propeller work conditions** – the high values of a wake which are specific for fishing vessels, cause that the non-homogeneous velocity field of water appears in the propeller disc area. In order to unify the velocity field and improve propeller effectiveness the following may be installed:

- **before propeller nozzles** – are produced in the form of properly profiled half rings welded to the hull at the stern part. Advantages may include: the reduction of the wake coefficient, propeller efficiency improvement, the rise of additional thrust directly affecting the hull, damping of longitudinal oscillations while sailing at stormy weather. The installation of such nozzles, due to the increase of the water stream velocity flowing on the propeller, requires that

propellers of the appropriate angle of attack of blades be selected;

- **propeller nozzles** – placing the propeller inside the nozzle of profiled cross-section is expedient at vessels travelling at slow speed and where the propellers are highly loaded. Such work conditions for drive system occur at fishing cutters using active fishing gear. The main advantage of the nozzle is to produce additional thrust force applied to the hull which sums up with thrust force generated by the propeller. The increase of thrust force during trawling at the speed in the range from 2 to 5 knots may equal from 20 to 10% respectively. Additional advantages arising from the use of propeller nozzles, with the exception of those listed previously before propeller nozzles, are: propeller protection against damages caused by fishing gear and ice, stability improvement, course steadiness, additional improvement of propeller performance by reducing water flow from the suction part to the face of the propeller, particularly at the tips of the blades. The maneuverability deterioration and lower propulsion efficiency at reverse motion are a disadvantage. The most common are the nozzles of Kort and Rice type which may be delivered together with appropriately selected propellers;
- **hull fins and turbulators** – they are used in order to improve the conditions of water flow on the propeller. Hull fins are welded to the hull directly over the propeller at the shortest distance from it. Additionally, during sailing in stormy conditions the hull fins reduce the risk of propeller surfacing and injecting air under the surface of water. While turbulators are made of a number of small blades welded to the hull in the place of boundary-layer separation with the result that the boundary-layer mixes with water beyond the reach of the boundary-layer. The result is the reduction and the homogenization of the velocity of water inflow on the propeller.

The advantages of the above solutions are: increased propeller performance, the reduction of vibrations and noise level, the reduced intensity of propeller cavitation process. While the increase of hull resistance value is a disadvantage.

### Energy saving operational activities

The most important measures in that field which contribute to the reduction of fuel consumption by the energy systems of fishing cutters, are as follows:

- **maintaining optimal condition of the hull and the propeller**

The hull technical condition significantly affects its resistance in the aquatic environment. Regular inspections of underwater hull should be carried out. Dents and organisms that cover the hull should be removed as well as damage to paint. Additionally, the resistance value may be reduced applying paints reducing friction factor or antifouling paints and grinding and maintaining welds joining hull sheets. Likewise, the propeller performance may be maintained by polishing blades' surface and covering them with paint preventing fouling by sea organisms and reducing the friction factor.

- **application of planned service system**

Servicing, according to the recommendations of producers, shall ensure that the machines and the devices of energy system for fishing cutters will be maintained in good technical condition. Useful in controlling technical condition is to equip the elements of energy system with control and measurement devices, in particular with fuel meters or instantaneous fuel consumption gauges. The level of training and professional experience of crew members are also very significant.

- **maintaining proper vessel draught and trim**

Vessel draught and its trim have considerable impact on the hull resistance which in turn affects the amount of fuel consumed by propulsion system. When draught is changed, the value of the trim, in which the resistance is lower, also changes. The vessel draught value depends on the quantity of inventories taken on board, and an optimal trim may be obtained by proper inventories and fish caught deployment and ballasting.

- **voyage planning**

The hull resistance and the quantity of fuel consumed are subject to velocity and sea current directions, the height and the direction of waves, and the strength and direction of the wind in relation to a cutter course. Therefore, it is recommended when planning cruise to use weather and nautical services. The optimization of velocity during a cruise is widely and rightly recognized as a basic measure for the significant reduction of fuel consumption by fishing cutters. In order to complete the task it is necessary to provide instantaneous fuel consumption gauge for fuel system. It also requires from the crew to learn and be able to interpret the propulsion characteristics of a particular cutter in different operational conditions.

## Energy saving logistic activities

The most significant logistic activities may include:

- **voyage time reduction without load**

In practice, this means that the choice of Fisheries is the nearest port of the vessel or by the nearest port to the fishing stay or selling fish. It is also very important information on the actual waiting time for unloading at the port. It would allow for adjusting velocity to a foreseen unloading time.

- **crew qualifications and training**

The selection of crew members of the high technical knowledge level and professional experience allows for planned and deliberate operation of cutters in accordance with the management requirements for efficient energy economy. The level of knowledge may be improved by crew trainings on the management of the energy economy and on the rules for the cooperation of particular energy system devices.

## Conclusions

The most of the energy saving activities analyzed in the paper are related to the reduction of fuel consumption. Forecast savings in fuel consumption arising from the application of energy saving technologies are presented in table 2 [4, 7, 8].

Table 2. Forecast savings regarding fuel consumption upon application of technological innovations at fishing vessels

Innovation	Forecast reduction of fuel consumption [%]
New structures of internal combustion engines	2–6
Hull shape optimization	8–10
Propeller shape and selection process optimization	3–6
Application of paint reducing friction coefficient	1–2
Grinding and maintenance of welds and hull and propeller	2–5
Hull trim optimization	1–2

The savings included in table 2 will be achieved upon having the technological innovations implemented at the design stage, and at vessels in operation during their repairs and modernization. In the case of fishing vessels, funding from the European Fisheries Fund is granted for specific modernization activities which aim at the reduction of energy consumption and the impact on the environment and work safety improvement. However, they do not grant covering total project cost (mostly from 40% to 60%) [6]. The detailed scope of moderniza-

tion and expected effects should be developed by construction offices experienced in designing and project implementation for specific vessels such as fishing vessels. In addition to the energy saving, technological projects mentioned herein, innovative actions are also worth to be considered, such as use of gas as the fuel for fishing cutters [9] and the catalytic processing of petroleum fuels [10, 11].

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